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SOME QUANTITATIVE MEASUREMENTS OF MINERALS OF THE NICKEL–ERUPTIVE AT SUDBURY.

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This paper reports some detailed examinations and measurements of thin sections and polished surfaces of a series of specimens from Sudbury, Ontario. The norite specimens show fracturing in minerals early to crystallize and not in others, indicating dynamic action during solidification. The sulphides are found to be related to the minerals which crystallized at a late stage from the norite.

The nickel-eruptive is well known as a Keweenawan sill intrusive between rocks of Huronian age; and together with them it forms the Sudbury syncline. The eruptive is made up of two phases, the micropegmatite above being considered a differentiate in place from the same magma as the norite below. The micropegmatite, as the name implies, consists chiefly of micrographic intergrowths of quartz and alkalic feldspars; the norite is characterized by more basic feldspars, by ferromagnesian minerals, and by the basic accessories usually found in rocks of the gabbro family. The original pyroxenes of the norite have been altered to chlorite and secondary biotite and hornblende. That this alteration is not a superficial one is shown by the fact that drill cores from a depth of over one thousand feet reveal the same alterations in the norite as those found nearer to the

surface.[1] The nickel ores occur as sulphide masses near the bottom of the norite.

There are in general two views regarding the genesis of the Sudbury nickel-copper ores, one favoring their deposition by

TABLE I.

ESTIMATED MINERAL PERCENTAGES IN THE NICKEL-ERUPTIVE, TO SHOW THE VARIATION FROM TOP TO BOTTOM OF THE MASS.

(For location of samples see Fig. 24.)

Number of Specimen	Amount of Quartz (Free Quartz and Quartz in Pegmatite)	Amount of Graphic Intergrowth (Pegmatite)	Amount of Perthitic Intergrowth (Often a part of Pegmatite)	Amount of Feldspar (Including Microperthite)	Amount of Frero-magnesian Minerals	Range in Composition of the Feldspars
38*	50%	60%	6%	40%	10%	Orthoclase, perthite, albite, oligoclase, andesine
39	37	50	8	53	10	Orthoclase, perthite, oligoclase, andesine
40	35	6	52	55	10	Perthite, oligoclase, andesine
41	30	8	15	60	10	Orthoclase, perthite, oligoclase, andesine
42	20	35	18	65	15	Oligoclase, andesine
63	28	10	8	50	22	Perthite, oligoclase, andesine
43	10	10	6	70	20	Perthite, oligoclase, andesine
44	5	0	0	85	10	Oligoclase, andesine
46	5	0	0	80	15	Oligoclase, andesine
64	5	6	6	75	20	Perthite, oligoclase, andesine, labradorite, bytownite
Seven specimens at the base of norite	25	15	13	50	25	Perthite, oligoclase-labite, oligoclase, andesine, labradorite, bytownite

segregation from the associated norite, and the other referring them to a hydrothermal origin. Advocates of the former theory are[2] Browne, Barlow, von Foullon, Coleman, Thomas, Bracken-

[1] Coleman, A. P., Ont. Bur. Min., XIV., Pt. 3, p. 111, 1905.

[2] Browne, D. H., "Segregation in Ores and Mattes," *School of Mines Quarterly*, XVI., July, 1895.

Barlow, A. E., "Origin, Geologic Relations, and Composition of Nickel-Copper Deposits of the Sudbury Mining District," Rpt. Can. Geol. Surv., 1904.

von Foullon, Baron, "Ueben einige Nickelerzvorkommen," Jb. d. k. XLII., p. 276, 1892.

bury, Daly, Lindgren, Stokes, St. Clair, and Beck, the latter also favoring "thermal enrichment." Those who uphold the hydrothermal theory are[3] Campbell, Knight, and Dickson. Still others,[4] notably Howe, and Tolman and Rogers, believe in some modification of the magmatic hypothesis.

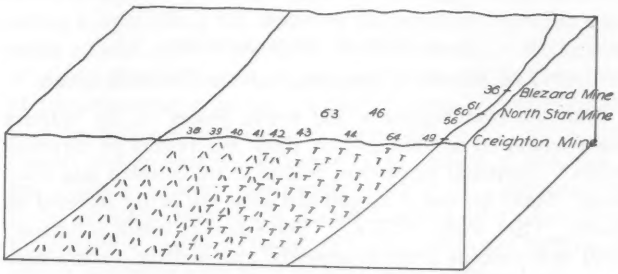

FIG. 24. Ideal section showing approximate location of specimens with respect to geologic surroundings.

Coleman, A. P., "Classification of the Sudbury Ore Deposits," *Trans. Can. Inst. Min. Eng.*, 16, p. 183, 1913; "The Nickel Industry," Can. Geol. Surv., M. B. 170, 1913.

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Lindgren, W., "Mineral Deposits," McGraw-Hill, 1913.

Stokes, Ralph, Discussion, *Min. World*, September 28, 1907.

St. Clair, Stuart, "Sudbury Nickel Ores," *Min. and Sci. Press*, 213, August 15, 1914.

Beck, R., "Microscopy in Economic Geology," *Eng. and Min. Jour.*, p. 1087, 1913.

[3] Campbell, William, and Knight, C. W., "Notes on the Microstructure of Nickeliferous Pyrrhotite," ECON. GEOL., II., pp. 350–366, 1907.

Knight, C. W., *Eng. Min. Jour.*, 101, p. 810, 1916.

Dickson, C. W., *Am. Inst. Min. Eng.*, Vol. 34, pp. 1–67, 1904.

[4] Howe, E., "Petrographical Notes on the Sudbury Nickel Deposit," ECON. GEOL., 9, pp. 505–522, 1914.

Tolman, C. F., Jr., and Rogers, A. F., "A Study of Magmatic Sulfid Ores," Bull. Leland Stanford Jr. Univ., 1916.

In the summer of 1916 the writer visited the Sudbury district and collected specimens from the Worthington and Frood-Stobie offset deposits, and from the Creighton, North Star, Mt. Nickel, Blezard, and Garson mines along the lower norite contact. Two traverses were made across the outcrop of the eruptive, one along the Lake Whitson road, and the other north of the Garson mine.

I. A STUDY OF THIN SECTIONS.

(*A*) *The Mineral Composition of the Nickel-Eruptive.*

Both the micropegmatite and norite phases of the eruptive when examined in thin section show the results of dynamic action.[5] Euhedral plagioclase feldspars are oriented and fractured. Many are badly warped and some are partly replaced by quartz. (See Plate XXXV.) Some norite, which is unfractured and contains fresh hypersthene and diallage, occurs near the margin of the area, but this is probably the "older norite" formed prior to the intrusion of the nickel-eruptive.

While the micropegmatite phase is fairly uniform in composition, it grades abruptly into the norite and the norite varies a good deal. Table I. and Fig. 24 show this variation in a series of specimens taken in the two traverses from the micropegmatite outward to the lower contact of the norite. The measurements of the thin sections were only approximate but they probably give a correct general idea of the variation. A number of the results were averages of several specimens from the same locality and the data for the base of the norite are averages of seven sections, all somewhat alike, from the marginal deposits. The Blezard, North Star, and Creighton mines are represented. It should be noted that the total constituents are the quartz, the feldspar, and the ferromagnesian minerals. It was nevertheless advisable to list separately the proportions of micropegmatite and perthite, and also to show the range in composition of the feldspars.

It is noteworthy that quartz, graphic intergrowth and microperthite increase and decrease together. The reason for this agreement lies in the fact that quartz is part of the graphic inter-

[5] Dickson, C. W., *Trans. Am. Inst. Min. Eng.*, p. 45, 1903.

growth and that the perthitic feldspars are in most sections associated with quartz in that graphic intergrowth. This triple intergrowth fills the spaces between euhedral crystals of plagioclase. The perthitic feldspars resemble microcline, but are distinguished by their varying optic character.

The transition from the zone of micropegmatite to norite occurs a little above the center of the eruptive (between specimens 42 and 43). There is an abrupt decrease in the amount of quartz, pegmatite, and perthite, and increase in the proportion of ferromagnesian minerals. A short distance below this transition the norite is practically an anorthosite, with only a little chlorite and secondary hornblende. The texture of this rock is not diabasic; coarse, idiomorphic crystals of plagioclase are found generally oriented and fractured, with a little quartz filling the interstitial spaces. The graphic intergrowth and perthite are wholly lacking in some parts of this "anorthosite."

While quartz and acid feldspar are almost entirely absent from some central zones in the norite, it is noteworthy that near the

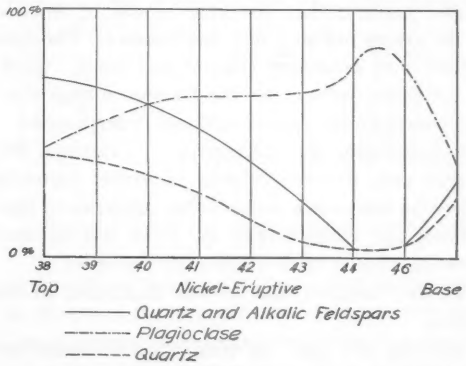


FIG. 25. Curve showing relative proportions of certain minerals and intergrowths in the Sudbury norite.

The plagioclase is that not in pegmatite, the quartz is the total quartz, and the quartz plus alkalic feldspars is mainly pegmatite.

Attention is called to the decrease of quartz and pegmatite in the anorthosite-norite and to their increase again at the base of the norite.

base of the norite they are again more abundant. See the curve of variation, Fig. 25. There are slight differences in the upper and lower occurrences. In the lower rock, quartz is less abundant and perthite occurs in more places as grains interstitial to the plagioclase.

The average feldspars become more acid as quartz increases, though the greatest range of feldspars is found near the base of the norite. The feldspars were studied with care as to sign, index, and extinction, but since a number were zoned, the range recorded does not always indicate two associated feldspars of the same generation.

(*B*) *Measurements Concerning the Structure and Petrographic History.*

Table II. contains a record of the relative number of fractured grains of (1) feldspar, and (2) quartz, and (3) graphic intergrowths of quartz and feldspar. In determining the percentage of grains fractured it was thought, since the rocks were of granitoid texture, that no error would be introduced by ignoring the grains below .5 mm. in diameter. The fissures are usually filled with secondary chlorite and biotite, much of the latter of the green variety; but the fracture fillings also include secondary hornblende, quartz-feldspar intergrowths, quartz, magnetite, pyrrhotite, and chalcopyrite. Fractures filled with chlorite were seen to cross chlorite of earlier formation; and similar chlorite veins cross some of the sulphides in the ore deposits. These late chlorite veins are much less numerous than the hornblende-chlorite veins in the early fractures.

Table II. also contains data on the occurrence of magnetite and sulphides.

It is clear that over half the plagioclase feldspars have been fractured. Quartz is much less commonly fractured than the plagioclase. The point is especially significant when it is considered that quartz often extends poikilitically around several plagioclase crystals, some of which may be fractured. One of the most remarkable features is that with the exception of one

TABLE II.

FRACTURING IN THE NICKEL-ERUPTIVE.

Number of Specimen d = Duplicate	Orthoclase Crystals Fractured	Orthoclase Crystals Unfractured	Plagioclase Crystals Fractured	Plagioclase Crystals Unfractured	Quartz Grains Fractured	Quartz Grains Unfractured	Quartz-feldspar Intergrowths (Micropegmatite) Fractured	Quartz-feldspar Intergrowths (Micropegmatite) Unfractured	Magnetite Associated with Fractures	Magnetites Not Associated with Fractures—Usually Surrounded by Biotite, Etc.	Sulphides Associated with Fractures or with Secondary Minerals in Fractures.	Sulphides Surrounded by Biotite, Free Quartz, Etc., and Not Apparently Related to Fractures.	Sulphides enclosed in Quartz-feldspar Intergrowths (Micropegmatite)
38	1	4	15	13	6	8	0	112	0	0	0	0	0
39	5	6	8	12	0	12	0	50	0	0	0	0	0
40	0	0	12	10	5	24	0	2	0	0	0	0	0
41	2	2	18	5	1	3	0	25	0	0	0	0	0
42	0	0	22	15	0	1	1	42	0	0	0	0	0
43	0	0	18	17	2	9	0	19	37	120	6	3	20
43d	0	0	18	15	1	3	0	14	17	115	3	3	15
63	0	0	16	13	3	8	0	10	30	84	0	0	0
44	0	0	61	25	2	10	0	0	2	0	4	0	0
44d	0	0	68	27	0	5	0	0	2	0	4	2	0
46	0	0	53	7	1	7	0	0	2	0	6	11	0
64	0	0	83	18	1	11	0	6	0	0	22	0	80
36	0	0	30	6	0	12	0	3	0	38	6	1	8
56	0	0	53	16	3	8	0	7	1	11	13	0	32
56d	0	0	37	1	4	8	0	5	8	15	6	1	15
61	0	0	15	16	2	17	0	14	3	12	3	1	60
61d	0	0	17	11	0	11	0	0	10	6	6	5	0
60	0	0	55	12	1	7	0	4	15	26	6	8	12
49	0	0	1	8	0	5	1	37	3	0	13	5	300
Total 19	8	12	610	247	38	169	1	351	130	424	95	40	507
Av. per Sec...	.4	.6	32	13	2	9	.05	18	7	22	5	2	26
Cf. %	45%	60%	71%	29%	18%	82%	28%	99.72%	23%	77%	71%	29%	

rock from Creighton, none of the micropegmatites are cut by any of the fractures developed by the dynamic metamorphism. This rock near Creighton is largely made up of a graphic intergrowth of quartz and microperthite. It is fractured, and the fracture filled with a poikilitic intergrowth of the same minerals —quartz and microperthite. In most of the rocks the pegmatite areas are interstitial among plagioclase grains, and fill fractures that have developed in the plagioclase. With one minor excep-

tion, each section studied showed the same tendency as the general average. Fig. 26 shows graphically how much more fracturing occurs in the plagioclase than in the more acid minerals. To complete the data it would be well to have measurements of the fractures in the ferromagnesian minerals, but this was impossible, because they were thoroughly recrystallized. They

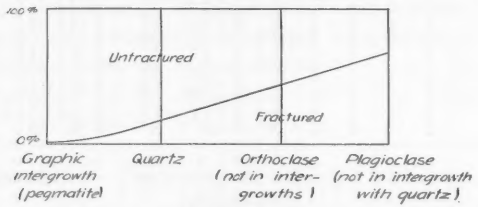


FIG. 26. Curve to show relative fracturing of essential minerals in the nickel eruptive. It will be noticed that the minerals last to form have suffered least fracturing.

were probably even more fractured than the plagioclase, for they formed early and were not very resistant.

The sulphides show a greater association with fractures than does the magnetite; but the sulphides in fractures and with basic minerals are nowhere as abundant as those enclosed in micropegmatite. It is noteworthy that sulphides are intimately related to this micropegmatite wherever the two are to be found in the same section. (See Plate XXXVI., *A*.) The lateness of crystallization of the sulphides is also shown by their occurrence interstitially between euhedral plagioclase crystals. (See Plate XXXVI., *B*.) The association of the sulphides with this late magmatic intergrowth is significant in a study of their genesis.

(*C*) *Ore Minerals of the Norite.*

Magnetite was not found in important concentrations, but the two traverses made across the norite showed systematic variations. The magnetite was found most abundant at a horizon not far below the gradation from micropegmatite to norite. From that point downward it was found in varying amounts, associated in some places with the sulphides.

The sulphides occur at several horizons, as shown in a general way by Table II. and Fig. 24. As has been pointed out by Coleman, the size of the ore particles included in the norite increases towards the base of the eruptive so as to bring about a transition first from ore in norite, to norite in ore, and finally to massive ore. The latter is scarcely ever free from silicates microscopically visible. Two points need especial emphasis: (1) ore masses often surround idiomorphic plagioclase; (2) ore particles, though variable in size, are enclosed in the quartz-feldspar graphic intergrowths.

(*D*) *Sulphides in Rocks other than the Norite.*

The ore bodies, having formed at the base of the norite, have in many cases a wall rock of other material than the norite. A sample of pyroxenite from west of the station on the third level of the Worthington mine shows a sharp contact with chalcopyrite; the pyroxene is largely altered to chlorite and amphibole. There is a vein of quartz, and near it, chalcopyrite intergrown with blades of clinochlore. Several specimens of graywacke schist taken from the dump of the Mond Nickel Company's Frood mine, from a stope in the Stobie mine, and from southeast of the shaft on the eighth level of the Garson mine, show stringers of sulphides apparently introduced after the rock was cemented. Specimens from the Blezard mine have sulphides acting as a cement in coarse conglomeratic quartzite. Near the ore is a chloritic schist in which veins of later spherulitic chlorite cut that of an earlier age. A similar relation is to be seen at the Stobie mine where chloritic veins cut sulphides which were earlier introduced into schist. Altered greenstones occur at the Canadian Copper Company's No. 3 mine and at the Mt. Nickel mine. Into these rocks sulphides have been introduced through fissures. In a specimen from the former, there is a rounded grain of quartz-feldspar intergrowth, completely enclosed by ore. No other such intergrowths have been reported in the greenstones. It is noteworthy that in all these rocks, except the main norite (pyroxenite, graywacke schist, quartzose conglomerate, and greenstone), the sulphides have structural relations indi-

cating introduction after solidification of the rock; and the rocks near the sulphides are hydrothermally altered.

Another type of rock outcrops north of the open pit at the Blezard mine and not unlikely is the "older norite" which Coleman[6] has suggested occurs here and at many places along the norite contact. The "older norite" is characterized by unaltered hypersthene and very slightly altered diallage, by the lack of any shattering or strain effects in the feldspars, and by a "normal" order of crystallization; accessory sulphides and magnetite formed first. In these respects the older norite shows a marked contrast with the basic portions of the nickel-eruptive. The sulphides, moreover, show no signs of segregation.

II. WORK ON POLISHED SURFACES.

Polished surfaces of sulphides from the several mines show, under the reflecting microscope, varying amounts of pyrrhotite, pentlandite, chalcopyrite, and polydymite.[7] The observations confirm the conclusions from thin sections, as to the relation of the ores to the nickel-eruptive. They were late to crystallize, and associated with micropegmatite. Contacts of the ores with norite were both rounded and angular; as a rule smaller inclusions of rock in ore were rounded, while larger ones were defined more sharply. Much of the ore was intergrown with silicates.

Between the several sulphides of the norite, the relations are extremely variable. It seems certain that the definite order of formation, determined by Campbell and Knight, and by Tolman and Rogers,[8] does not hold for every specimen at Sudbury. In a series of similar specimens, or even in a single polished surface, one intergrowth will indicate certain sequences of growth, but another reverse the order.

In some of the workable ore deposits pyrite may be found. A

[6] Coleman, A. P., Can. Geol. Surv., Mines Branch, B. 170, p. 78, 1913.

[7] For mineral determinations recourse was had to Murdoch's tests by etching; acids were used for identification, and methods were checked on known material.

Murdoch, J., "Microscopical Determination of Opaque Minerals," J. Wiley & Sons, New York, 1916.

[8] *Op. cit.*

small amount was seen at the Stobie mine, and larger masses at the Mt. Nickel mine. Pyrite has been seen bordered by chalcopyrite, and by pentlandite, and intergrown with them. "Nodular" ore from the Worthington mine shows massive pyrite enclosing rounded masses of chalcopyrite, but this relation is not typical, for here rearrangement seems to have followed faulting in the ore body.

Polished surfaces from rocks below the norite show the same minerals as in the norite, with similar relations to each other, but different relations to the rock.

In resumé, polished surfaces of ores from all occurrences show interpenetrating sulphides. In all rocks but norite, however, the sulphides have apparently been introduced along fissures or along the schistosity. In the norite, the sulphides are intergrown with silicates.

III. INTERPRETATION OF THE DATA.

(*A*) *The Nickel-Eruptive.*

The data obtained favor the idea commonly held that the nickel-eruptive has differentiated in place, whatever the process or combination of processes may have been.

The orientation and shattering of feldspar crystals in the norite indicate dynamic action; and the occurrence of warped plagioclase and the replacement of plagioclase by quartz point to conditions of high temperature and pressure at the time of the dynamic action. The abundance of fractures in the plagioclase, their scarcity in the quartz, and their almost complete absence in the quartz-feldspar intergrowths are taken as indications that the schistosity developed during the crystallization of the magma. It would appear that the plagioclase and pyroxene had formed euhedral crystals, and that some of the quartz and alkali feldspar were still in a molten, very fluid state, when dynamic action occurred.[9] It is significant, in this connection, that even the thor-

[9] The idea that deformation of the invaded rocks occurred at exactly the critical moment, when it would find the magma part crystallized and the ore molten at the base, is considered improbable by Doctor Bateman, ECON. GEOLOGY, Vol. 12, p. 410. But this petrographic study indicates that some deformation of the intrusive at any rate did occur at that stage.

oughly fractured rocks show fractures that stop abruptly at the edge of feldspar grains. (See Plate XXXVI., *C*.) The presence of the micropegmatite and poikilitically interstitial quartz as fracture fillings in plagioclase is even stronger evidence. (See Plate XXXVI., *D*.)

The geologic history of the region indicates a general subsidence resulting in the "Sudbury syncline," since the time of the norite intrusion; and while this subsidence may have been prolonged through more than one period, it is entirely possible that it began in Keweenawan time, and possibly even while the nickel eruptive was still only partly crystalline. Certainly some movement of about such a type is clearly indicated by the condition of the rock.

Any deformation in such half-fluid magma would result in "filter-pressing." The liquid would be squeezed out in any direction where the pressure was relieved. Such a filter-pressed magma and the aqueous vapors usually associated with acid residues would more or less completely alter the pyroxenes already formed, to the hornblende and chlorite of the norite now found.

A question may arise as to the formation of the anorthosite phase of the norite. The rock is almost panautomorphic; it has not the usual xenomorphic-granular texture of anorthosite. By whatever process the mass may have been separated from the ferromagnesian minerals, it seems likely that the feldspar crystals grew nearly to their present size in a liquid matrix. This liquid, however, did not crystallize in place—did not grow on the euhedral crystals of feldspar, making them anhedra. It was probably filtered off, leaving only a little quartz and basic material. It is clear from the thin sections that some crystals were crushed and broken against the sides of others.

The acid rock near the ore at the base of the norite has been a stumbling block to several theories of the history of the eruptive. The acid material makes up nearly 20 per cent. of the mass and is too abundant and widely disseminated to be considered an addition from the outside. The norite is no more acid near the granite floor than where the floor is greenstone.

The acid minerals in the norite at the base are the same and have the same relation to each other and to the basic minerals that they have in the higher acid phases of the norite. It seems necessary, therefore, to refer the acid material to the same magma as the norite and ore. The idea of a filterpress, squeezing the mother liquor down, is suggested in a later paragraph as an explanation for its basal position.

(*B*) *The Ore Minerals.*

The sulphides are considered of magmatic origin. Their occurrence surrounding plagioclase feldspars shows that they crystallized after the plagioclase had formed distinct crystals. The abundance of sulphides with quartz-feldspar intergrowths, however, points to the solidification of the sulphides with the final solidification of the rock. The relations of the sulphides to each other in the workable ore are the same as in the norite. There is no sign of alteration or any other evidence to suggest that the masses of ore making up the workable deposits are in any way different from the less concentrated material in the norite. The introduction of all the ore, in the deposits and in the norite, from the deeper magma chamber or from some other external source, would require also the addition of all the acid material which surrounds the ores in the norite, and the improbability of this has already been pointed out.[10]

Not only do the sulphides show all the structural and paragenetic characteristics of segregations from magmas, but also a lack of association with any other type of activity competent to cause their deposition. The negative evidence, however, has sometimes been overstated. In proof of the independence of these ores from hydrothermal origin Tolman and Rogers state that all the secondary minerals with the exception of the hornblende are later than the ores. Veins of chlorite are described as cutting both rock and ore. Thin sections examined in the course of the

[10] The "intrusive" Creighton granite, supposed by Bateman (*op. cit.*, p. 413) to be a final argument against simple magmatic segregation, is not final until the intrusive character of the granite is more firmly established. See Coleman, A. P., ECON. GEOLOGY, Vol. 12, p. 427.

present work show that these veins of chlorite traverse chlorite developed at an earlier stage. There were, then, two stages of alteration, the first during the time of magmatic rearrangement and deformation of the eruptive, practically contemporaneous with ore deposition; and the second at some subsequent period. These later veins of hydrothermal minerals are, furthermore, so small and so uncommon that they have probably little bearing on the history of the deposits. The really significant alteration of the norite is the one closely following its intrusion and differentiation, and this change took place even before the completion of magma crystallization. Locally there is some hydrothermal action and some redistribution of pyrite and chalcopyrite near a few faults in the massive ore. Locally, too, there has been some cold water solution and redeposition, but on the whole both of these activities seem insignificant.

The rather common appearance of ore in schist and greenstone might at first seem incompatible with magmatic origin; but these ores are of low grade and are shown to be probably injected into the older rocks. This relation is not at all unlikely in view of the conditions of high temperature and pressure prevailing in the walls of the norite at the time of its deformation.

The ore minerals solidified at a late stage. If sulphide crystals formed throughout a half crystallized mass, no settling of importance could be expected. As a matter of fact the large bodies of sulphide occur at the bottom and it is likely that they separated through immiscibility with the liquid norite.

In considering an immiscible separation, it seems likely that while part of the ore separated in masses at the bottom, many globules which had not reached the bottom were locked up, still molten in the norite, by the crystallizing plagioclase. At the time of the dynamic action these molten sulphides, distributed through the partly crystalline norite, would be, in common with the still liquid feldspathic material, filterpressed away from the interior and driven out wherever pressure was relieved. With molten ores at the base and a probably molten acid differentiate at the top of the norite, both places would offer relief from

pressure. Possibly the acid residuals, being the lightest of the still molten materials, would be likely to accumulate at the top, while the ores, being heavy, would more likely be filterpressed downwards towards the outer edge of the syncline; but such a gravity effect during filterpressing would probably fail to be a sharp separation. Thus one can account for the sulphides high up in the norite, and for the quartz and pegmatite so characteristic of the lower part of the norite.

In any case, immiscible separation would result in a sheet of molten ore below the norite while that rock was in its final stages of crystallization. There is little doubt that deformation would cause blocks of the norite to sink for a short distance into the molten sulphides and that, correspondingly, stringers of the sulphides would wriggle upward in the hanging wall. The coarse norite breccias cemented by ore which are strikingly displayed on fresh faces in the Worthington and other mines probably show the result of such intrusion.

IV. CONCLUSIONS.

It is known that the Sudbury norite is schistose and brecciated, and in an extensive set of material it is found that the abundant fractures are limited to the minerals first to form. This schistosity therefore certainly developed before the norite had entirely solidified, possibly at the time of formation of the Sudbury syncline. Filterpressing might well accompany such late magmatic deformation.

The sulphides, the quartz, and the micropegmatite were all late in time of crystallization. The interstitial quartz and pegmatite formed an essential part of the eruptive; they surrounded the sulphides in the norite and crystallized with them, or at a later time. In the segregations the sulphides display the same relations of intergrowth with each other as in the norite. It is therefore maintained that the sulphides are chiefly of magmatic origin. They were still molten when the norite was deformed and altered. The acid material, molten at the time of deformation, probably contained a good deal of water and reacted on the

EXPLANATION TO PLATE XXXV.

FIG. A. Anorthosite of norite, showing orientation of subhedral grains; × 40.

FIG. B. Warped plagioclase in norite; × 40.

FIG. C. Plagioclase of the norite, partly replaced by quartz of a late magmatic stage; × 70.

FIG. D. Chlorite and quartz filling fissures in plagioclase; × 70.

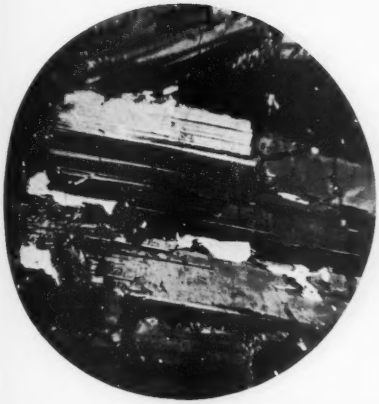


FIG. A.

FIG. B.

FIG. C.

FIG. D.

FIG. A.

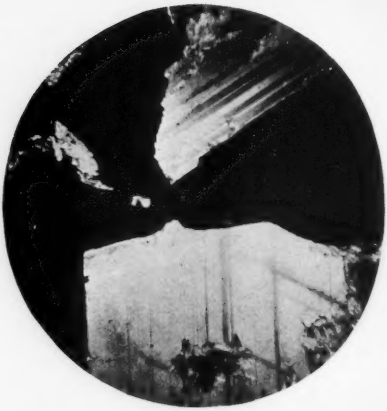


FIG. B.

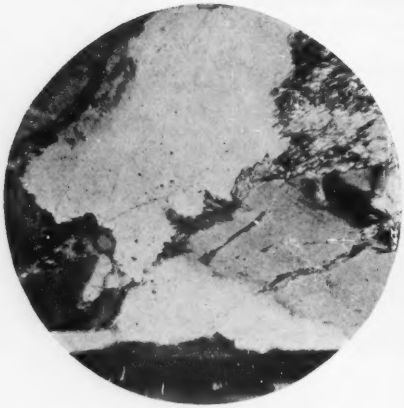


FIG. C.

FIG. D.

EXPLANATION TO PLATE XXXVI.

FIG. A. Graphic intergrowth of quartz and alkali feldspar enclosing sulphides; Creighton; × 70.

FIG. B. Ore minerals surrounding plagioclase; × 40.

FIG. C. Fractures crossing plagioclase but not extending into the adjoining quartz; × 40.

FIG. D. Micropegmatite filling fissures in fractured plagioclase; × 70.

early pyroxenes to form chlorite and secondary biotite and hornblende; it also corroded and replaced the plagioclase. There was a little hydrothermal alteration later, but it was relatively insignificant. Where sulphides are found in rocks other than norite they are injected, possibly as a part of the segregated mass, or as an emanation from it.

Some of the ores are known to have formed liquid masses below the norite differentiate and to have intruded and brecciated it. The chief separation may therefore be attributed to immiscibility of the ores and magma at a certain stage of cooling; but it is suggested that some of the ores and acid mother liquor may have been filterpressed or squeezed out of the plastic norite at the time of its deformation.

Acknowledgments are especially due to Dr. W. H. Emmons and Dr. F. F. Grout, of the University of Minnesota, for their suggestions and valuable assistance during the preparation of this paper.

THE PETROLEUM GEOLOGY OF THE ISTHMUS OF TEHUANTEPEC.

BURTON HARTLEY.

INTRODUCTION.

The great petroleum wells of Mexico, such as Dos Bocas, Juan Casiano, Potrero del Llano, and others, have long attracted such attention that they have tended to overshadow the fields of lesser importance on the Isthmus of Tehuantepec and in the adjoining states of Tabasco and Chiapas.

The Isthmian production, however, is obtained from a type of structure very different from that of the Tampico-Tuxpam region—namely from salt domes. There are many widely varying theories regarding the origin of salt domes, and it is not the purpose of this paper to enter into a discussion of them, but to point out similarities between the Isthmian salt domes and those of the United States and Europe.

During the construction of the Ferrocaril Nacional de Tehuantepec numerous seepages of asphalt and liquid petroleum were found in the region from Coatzacoalcos back to the mountain front south of Santa Lucretia. Exploration was undertaken somewhat later by an English company and after a number of wells had been drilled, oil was obtained in the San Christobal field. Drilling and exploration have since that time been more or less continuous with the result that new pools have been opened and a production obtained that, had it not been small when compared with that of the prolific northern gushers, would have attracted far more attention than it has.

The region from Coatzacoalcos back to the mountain front is the typical coastal plain of the Gulf of Mexico, rising gradually southward from the Gulf and circumscribed by the southeastern continuation of the central Mexican Plateau. The drainage, which is generally northward, is controlled by two major streams

and their affluents. The Coatzacoalcos River with its branch, the Uspanapa, drains practically all the northern Isthmian region, and the Rio Tonala, forming the boundary between the states of Vera Cruz and Tabasco, drains the eastern border.

GEOLOGY.

General Statement.

The coastal plain is covered with a residual mantle of soil and a dense tropical jungle that obscures most of the hard rocks of the region. The only exposures are found in the smaller arroyos and in deep artificial cuttings. This makes extremely difficult any study of the general geologic features of the region and leaves much to conjecture.

Inasmuch as the pre-Tertiary rocks seem to have little or no bearing on the petroleum problem, they may be dismissed from consideration with the brief statement that they consist mainly of limestone and slate of Cretaceous age.

Tertiary System.

Miocene.—The lowest Tertiary rock exposed in the coastal plain is blue marl of very great thickness. It is somewhat massive toward the base and in many places contains limestone lenses and concretions which contain a few fossils, mainly of the genus *Mytilus*. Alternating with the limestones are a few sandstones which increase in number and thickness toward the top of the formation. This marly formation is correlated with the Miocene of Chiapas and Tabasco, which is well-developed and abundantly fossiliferous. The thickness of the formation is variable, but where complete, it is probably 2,000 or 2,500 feet.

Pliocene.—Overlying the formation provisionally referred to the Miocene and probably conformable upon it is a mass of sandstone, generally blue and argillaceous, but in places very micaceous. Occasional brown to reddish beds have been found in this formation and rarely a few calcareous concretions. The formation usually contains many very brittle fossils, among which

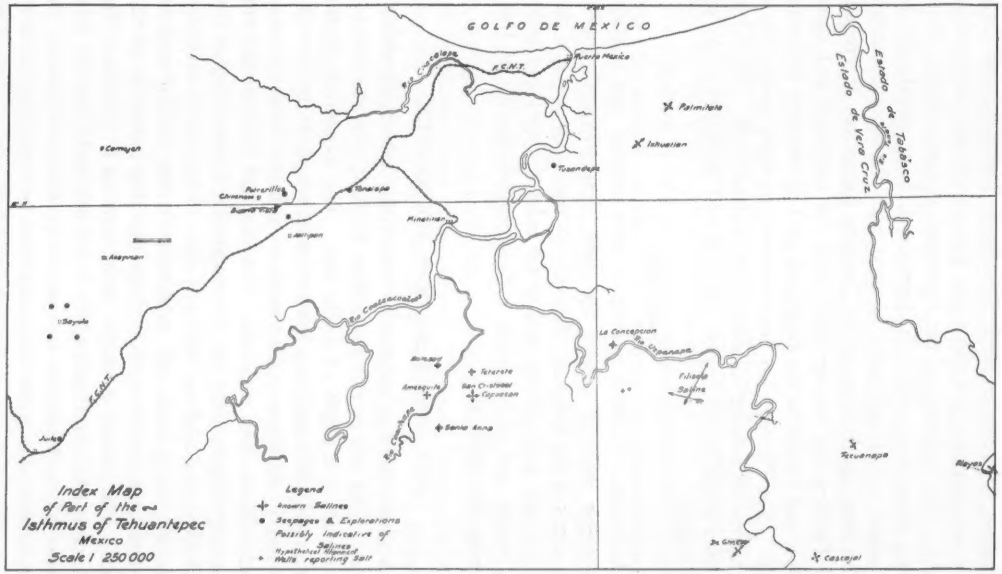

GOLFO DE MEXICO
Puerto Mexico
F.C.N.I.
Estado de Tabasco
Estado de Vera Cruz
Palmitola
Ishuatlan
Tuxtepec
Comayun
Petrarillo
Chinameca
Tonalapa
Minatitlan
Acayucan
Sayula
Jaltipan
Texistepec
Jaltipan
La Concepcion
Coatzacoalcos
Minzapa
Tetetate
Amesquite
San Cristobal
Capoacan
Santa Anna
Filisola
Salina
Tecuanapa
Cascajal
Juhua
Index Map
of Part of the
Isthmus of Tehuantepec
Mexico
Scale 1 250 000
Legend
Known Salines
Seepages & Explorations
Possibly Indicative of
Salines
Hypothetical Alignment
Wells reporting Salt

FIG. 27.

Amusium, Pectunculus, Arca, Dentalium, Turritella, and *Pecten* are most numerous, but also a few gasteropods and some echinoderms. The thickness of the formation is questionable, the top having never been definitely determined, being usually eroded, but where remaining partly covered with Pleistocene material.

The areal distribution of the Tertiary formations is irregular. The Tertiary sea transgressed from the northeast and spread further and further to the south and west during each succeeding epoch. The Pliocene has been removed in many places leaving large areas of isolated Miocene as the surface rock. No Eocene has been found in this region, but it is well developed to the east in Tabasco.

Quaternary.

Pleistocene.—A thick mantle of both original and reworked Pleistocene material covers the older formations throughout large areas of the Isthmus. Gravel composed of quartz and chert pebbles; red, pink, bluish, and cream colored clays; and yellow, red, brown, and bluish sands with a general absence of fossils make up this material.

SALT, GYPSUM, SULPHUR, AND DOLOMITE.

These are the four substances universally associated with salt domes. The salt is the usual type of rock salt and has been penetrated to a depth of 1,980 feet. The associated gypsum, usually anhydrite and very often selenite, ranges from zero up to 200 feet in thickness. Free sulphur is found intimately associated with the other minerals. The so-called dolomite is a limestone only slightly dolomitic, the magnesian content ranging from one half to two and one half per cent. The rock is variable in character, being hard and impervious in one locality and soft and porous in another and in places carrying inclusions of chert bands. The thickness ranges from zero up to 30 feet. That the rock is a chemical precipitate is beyond doubt, but the actual manner of its formation is open to question—a question that presents for controversy the many theories regarding the origin of salt domes. In the light shed through the study of the better

known European salt domes, the writer believes that this so-called dolomite is the residue left by the partial dissolution by surface waters of the top of the salt plug. The irregular distribution and character of the dolomite and its close association with gypsum certainly lend color to this hypothesis. In many of the domes the dolomite has become the oil container.

SALT DOMES.

The Isthmian Salt Domes are Two-fold in Character.—True domes or quaquaversals and anticlines with a salt core in the apex, but not always penetrating to the surface. The presence of the salt dome is generally marked by seepages of liquid petroleum, solid asphalt, sulphur or salt water, with a few occurrences of grahamite.

The Ixhuatlan salt dome has the general form of a northeast-southwest anticline, surrounded by bluffs of blue Pliocene sandstone rising 200 feet above the level of the valley. The floor of the valley is covered with detritus and practically no hard rocks are exposed, but the wells enter the Miocene marl immediately after penetrating the residual cover. The marl carries a number of sands, some of which are productive of oil. The dolomite when encountered directly above the salt plug is generally hard and compact and, contrary to usual conditions, is barren of oil throughout.

The Filisola salt dome is of peculiar shape and wide extent, having northwest-southeast and northeast-southwest axes, each approximately five kilometers (a little more than 3 miles) long with the salt known to extend even farther toward the northwest. The salt dome is marked by a central surface depression that corresponds to the shape indicated by the axes and is surrounded by bluffs of Miocene marl which dips away from the central core at steep angles. The fact that a well in the center entered salt within several hundred feet of the surface, without passing through stratified rock, indicates that the salt mass originally reached the surface and had been dissolved out, leaving a basin which later became partly filled with debris. Several wells drilled

a considerable distance northwest of the center passed through the Miocene and also entered salt, showing a great longitudinal extent of the salt core.

The Palmitota salt dome may be roughly described as similar to the Ixhuatlan dome geologically and to the Filisola dome topographically.

The Cascajal salt dome is nearly a perfect dome, but in other respects it very closely resembles the Filisola dome, except that part of the central basin is filled with Pliocene detritus. On the rim of the basin and just within the Miocene bluffs there is a line of seepages part of the way around the dome, as though the oil, sulphur, and salt water had found an outlet to the surface along the line where the salt had been dissolved out.

The Tecuanapa salt dome is a northwest-southeast anticline without distinctive topographic features. The surface geology is largely obscured, but it is known that the Miocene is very close to the surface. The few sands encountered in the Miocene in this dome are water-bearing and the dolomite is productive of oil. In these respects it differs from the Ixhuatlan dome. A northwest-southeast fault has cut off the salt mass abruptly on the south side.

La Concepcion salt dome is practically a duplicate of Tecuanapa dome, except that the anticlinal axis is more nearly north-south. The dolomite cap at the San Cristobal-Capoacan salt dome shows a double dome upon a nearly east-west anticline. This salt dome has had a remarkably irregular production.

RELATION OF SALT DOMES TO OTHER STRUCTURAL FEATURES.

In northwestern Europe salt domes occur along rather well developed lines of weakness which follow more or less regular alignment. In Mexico the striking linear arrangement of the salt domes may mean a similar connection with lines of structural weakness. The Mexican salt domes may be divided into two systems, the trend of one being in a general northwest-southeast direction and parallel more or less closely with the mountain

front. Along such a line the Las Plyas, Tecuanapa, Filisola, and Concepcion salt domes are located. With this group should possibly be included the Soledad-San Cristobal salt domes and a hypothetical group in the vicinity of Potrerillos and Jaltipan. The suggested inclusion of the former group is based on the known existence of an anticlinal axis that, from a point southwest of La Concepcion, trends off from the main fold in a southwesterly direction toward San Cristobal. A parallel line to the south of this one would include the Cascajal, De Gheest, and San Cristobal group of salt domes.

The second system appears to have a linear arrangement along northeast-southwest lines. The major axes of many of the salt domes trend in this direction, and along such a line would be located the Palmitota, Ixhuatlan, and Teterete-San Cristobal-Santa Anna group of salt domes. The intersection of lines of weakness in the two systems seems to offer a plausible explanation for the cluster of salt domes composing the Soledad-San Cristobal group. The long line of seepages along the railroad also trends in a northeast-southwest direction, suggesting the possibility of an additional line thereabouts.

The suggested alignment noted above is of course tentative only. It should be remembered that similar relations have been assumed in the Gulf Coast salt domes of the United States, only to be disproved later by more detailed field work. There are very few indications of folds in the Isthmian region, hence it is not possible to say whether these lines, if they are proved to be lines of weakness, are folds or faults. The actual existence of superficial domes or anticlines at certain points is more likely to be the result of the penetration of the salt plug than the result of the crossing of folds or faults. In Europe salt domes are encountered in many places in synclines and this is explained by the assumption that lateral compression is greatest in deep-seated beds in such a structure. Similarly in the United States, the group of salt domes in Van Zandt and Freestone counties and vicinity in central Texas are located about in the trough

between the Balcones uplift and the Sabine peninsula. Small faults are present at a few points, but unfortunately they can not be traced.

ORIGIN OF THE OIL.

Little is known regarding the ultimate source of the Mexican oil, but it seems probable that it may have been derived from the Miocene marl.

THE HALOGEN SALTS OF SILVER AT WONDER, NEVADA.

J. A. Burgess.

The writer was pleased to find, during a stay at Wonder, Nevada, that the ore-body of the Nevada Wonder mine gave further opportunity for observing the occurrence of the halogen salts of silver. In a previous article on this subject,[1] describing the halogen salts of silver at Tonopah, Nevada, it was stated that the chloride, bromochloride, and iodide occupied fairly well marked horizons; their respective positions being downward in the order named. This sequence was explained as corresponding to the order of their deposition from percolating surface waters charged with haloid alkaline salts. It was very interesting to find that the arrangement of these secondary silver minerals at Wonder corresponded to that at Tonopah, and bore out the theory advanced to explain the order of deposition. There are, however, some differences between the two deposits that make it seem worth while to describe the ores at Wonder.

GEOLOGY AT WONDER.

Wonder is situated in Churchill County, Nevada, about 120 miles east of Reno. The climate is that of the arid regions of the Great Basin. The country is a complex aggregation of tertiary eruptives, including rhyolite, dacite, andesite, and basalt. Of these rocks the Wonder rhyolite is the oldest. It is a basic type of rhyolite, which, from its mineralogical and chemical composition, might well be called a quartz latite; but it has been so commonly known as the Wonder rhyolite, that it seems better not to change its appellation.

The ore-bearing veins of the district occur in this Wonder rhyolite, usually near small intrusive masses of a more acid

[1] Economic Geology, Vol. VI., p. 13, 1911.

rhyolite. They are characteristically composed chiefly of quartz and a white potash-feldspar. There are many of these veins in the district, most of which contain small deposits of silver-gold ore; but none of them, except the Nevada Wonder vein, has produced sufficient ore to pay for mining.

NEVADA WONDER VEIN.

The Nevada Wonder vein outcrops at the surface. It lies partly on the contact between the Wonder rhyolite and an intrusive body of dacite, but toward the north the vein leaves the contact and lies entirely within the rhyolite. The strike is N. 25° W., and the dip 75° E.

The ore consists of quartz rudely banded with feldspar. Oxidation extends to the 1,300-ft. level. The oxidized part of the vein forms the cleanest silver-gold ore, from a mining and milling point of view, that I know of. The gangue is made up of quartz, feldspar with its usual decomposition products, and occasional small quantities of fluorite. It is prevailingly stained yellowish-brown with limonite, although some of the ore is white. The silver is in the form of argentite and halogen salts, and the gold is both native and combined with the argentite. The oxide of manganese occurs only in small dendritic forms, except in unimportant local concentrations. Copper and lead occur only in traces. No zinc was found above the 1,300-ft. level, and there is practically no arsenic or antimony.

OCCURRENCE OF THE SILVER HALOIDS.

The silver haloids found at Wonder were embolite, iodobromite, and iodyrite, which are respectively the bromo-chloride, iodo-bromo-chloride, and iodide of silver. No cerargyrite was found. As at Tonopah, the percolating waters contained the alkaline salts of chlorine, bromine and iodine, which caused the selective precipitation of corresponding secondary silver minerals in separate horizons. There was this difference, however, that while at Tonopah the silver took the form of chloride, bromo-chloride, and iodide; at Wonder it took the form of bromo-

chloride, iodo-bromo-chloride, and iodide, the order being downward as named. The best example of this was in what is known as the Extension ore-shoot where embolite was found to a depth of 950 feet and iodobromite from that depth to the 1,300-ft. level. There was considerable overlapping of these zones, as would be expected, but they were sufficiently distinct to attract attention. Iodyrite was found in very limited quantity and in collectible amount only in one locality on the 1,000-ft. level, where in a hanging-wall branch of the vein, there was an unusually rich deposit of silver sulphide which had been shattered and partly oxidized. Iodobromite occurred in films and crystallized coatings throughout this mass, among which were some very pretty specimens. At the lower limits of this enrichment, a small pocket of loose iodyrite crystals was found lying immediately under rich fragments of ore. As at Tonopah, jarosite, the hydrous sulphate of iron, was prominent among the decomposition products associated with the iodyrite. It will be observed that, although this iodyrite was not found at the lower limit of the iodobromite zone, it was in a channel separated from the main body of the ore. In this position the rich ore had the effect of intensifying the precipitation of the chlorine and bromine and reducing their concentrations, until the solution was sufficiently weak in these elements to permit the precipitation of the iodide. In the main vein, however, the iodobromite zone extended to the lower limits of oxidation at the 1,300-ft. level.

While the iodide was uniformly precipitated separately from the chloride and bromide at Tonopah, it was, with the trifling exception noted, precipitated in combination with them at Wonder. The reason for this is apparently that the percolating solutions in the two places contained different concentrations of the chlorides, bromides, and iodides. Emmons says:[2]

> If, in a solution containing the three halogens, chlorides are vastly in excess, silver chloride will be precipitated first, even if bromides and iodides are present, for in a mixed solution the least soluble salts are not precipitated first, if a more soluble salt is present in sufficiently great concentration.

[2] William Harvey Emmons, "The Enrichment of Sulphide Ores," Bulletin U. S. G. S. No. 529, 1913, p. 115.

Evidently the concentration of chlorine was less in proportion to that of bromine and iodine at Wonder than it was at Tonopah.

The minerals associated with these halides were the quartz and feldspar of the vein with their usual decomposition products, limonite in comparatively small amount, manganese dioxide in very small amount, and wulfenite. The latter occurred in small amounts in the iodobromite zone, though there seems to be no obvious connection between the two. As previously mentioned, flaky jarosite occurred with the iodyrite, but not noticeably elsewhere.

It is noteworthy that no pure bromide of silver was identified at either Tonopah or Wonder, although I kept a close watch for it. The term "bromides" or "bromide of silver" is often loosely used among prospectors and others to describe various minerals of blue and green tints, but these on examination usually prove to be carbonates of copper.

The source of the halogen salts of the alkalies appears to be in the salt lakes that formerly existed in this region. Alkali flats, and salt beds of commercial importance, lie within twenty-five miles of Wonder. As far as I can ascertain, the salt accumulations of the Great Basin have not been tested for iodine or bromine, but Mr. Geo. Otis Smith has informed me that bromine was detected in the brines from Searles Lake, California. Doubtless, close analysis would show that they exist in practically all of these salt accumulations.

DESCRIPTION OF THE SILVER HALOIDS.

Embolite, Ag(BrCl), occurs as grayish-green, waxy, translucent coatings and groupings of deformed crystals adhering to the ore. Where the mineral is abundant, it is sometimes found in the form of loose crystals, often of cubical form, lying in cracks and openings. It is often associated with wulfenite. It has a perceptible odor of bromine. It is sectile and has no cleavage. The symmetry is isometric.

Iodobromite, 2AgCl, 2AgBr, AgI (Dana). The iodo-bromochloride occurs as light to dark olive-green, translucent, lustrous,

crystalline coatings, and loose, imperfect crystals. Crystal surfaces have a brilliant luster. The mineral has no cleavage and is sectile. It is associated with a small amount of wulfenite and an occasional loose crystal of iodyrite. The odor of bromine is apparent. The symmetry is isometric but perfect crystals are rare.

Iodyrite, AgI. The iodide is found in pockets of loose, sulphur-yellow crystals in cracks and cavities in the ore, and in occasional crystals associated with iodobromite. Symmetry, hexagonal hemimorphic. More completely described in the article on Tonopah. The mineral is sectile and has well-defined cleavage. It has a distinct odor that is slightly milder than that of iodobromite or embolite.

The odor of these minerals, as a class, is one of their most distinctive characteristics. though I do not know of its having been mentioned heretofore in print. It is best described as a drug-store or laboratory odor, as it reminds one strongly of the characteristic odors of those places, and is not as rank as the odor of chlorine or bromine gas. Of the specimens that I have at hand, embolite and iodobromite smell alike, though iodobromite is the stronger. The smell of iodyrite is milder and less penetrating than the other two. The odor of these minerals is sufficiently strong, so that on entering stopes where a deposit had been newly found, I have frequently been made aware of its presence through the sense of smell.

Note: Correction to paper on the "Halogen Salts of Silver at Tonopah," ECONOMIC GEOLOGY, Vol. VI., No. 1, p. 16 lines 7 and 8, should read: "Since it is a change from a less soluble to a more soluble form."

THE HEALDTON OIL FIELD, OKLAHOMA.

SIDNEY POWERS.

INTRODUCTION.

One of the most important and largest producing fields of Oklahoma is Healdton with a daily output of 57,000 to 63,000 barrels. Northwest of Healdton is the Loco field, where a small quantity of shallow oil and a large volume of shallow gas has been found. North of the Healdton and Loco fields are the Wheeler oil and gas field of small extent and now practically exhausted; the newly developed Graham oil field of small initial production; the new Fox field with enormous gas wells and two oil wells; and the Duncan gas field. West of Healdton 42 miles a new gas field is being opened near Walter, Cotton County, and 18 miles northwest of Healdton a new oil field is being developed on the Velma anticline (Fig. 28).

The Healdton field is 7 miles in length, 2½ miles in maximum width and extends from northwest to southeast across the northern half of T4S, R3W, Carter County. The development has extended from near the center of the anticline first to the northwest and later to the southeast, in which extensions the limits of production are now being determined. Production was the heaviest in the western portion of the field, gradually diminishing toward the north and abruptly stopping on the south. Until the discovery of deep sands in the Southeast Extension during the past year, the entire production of the field was from sands at depths of 800 to 1,150 feet.

Geologically, it has been found that the Permian "red beds" at Healdton are underlain conformably by Pennsylvanian shales and oil-bearing sands, and that the latter rest on the top of a buried ridge composed of Ordovician strata. The results of a study of the structural conditions as deciphered from well logs and from cuttings are given below.

GENERAL GEOLOGIC STRUCTURE.

Between the Arbuckle and Wichita mountains on the north, the Central Great Plains of Oklahoma and the Texas Panhandle on the west, the pre-Cambrian outlier of central Texas and the Cretaceous embayment on the south, a large area of southern

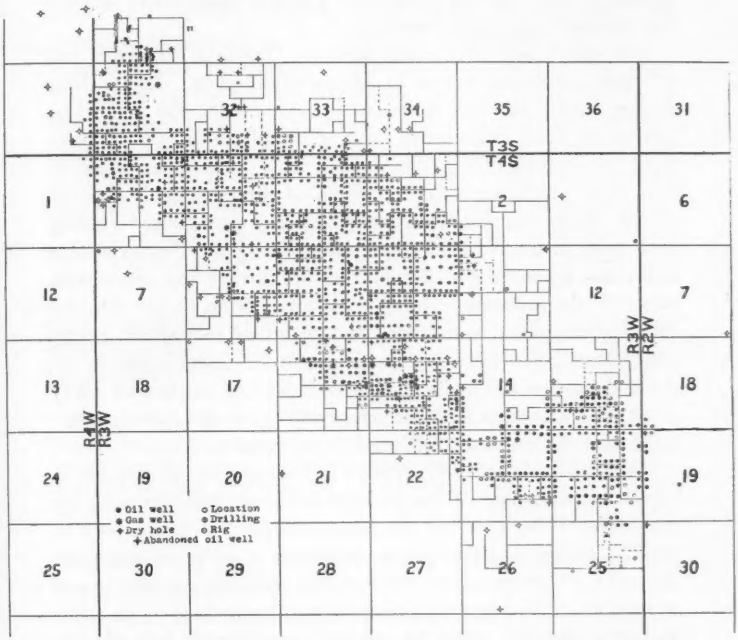


FIG. 28. Map of southern Oklahoma showing the location of oil and gas fields.

Oklahoma and north Texas is underlain by rocks of Permian age which form a broad synclinal trough, whose deepest portion lies in southwestern Oklahoma near the Red River. In southern Oklahoma the Permian sediments cover the Pennsylvanian and whatever masses of older rock may project through the Pennsylvanian. The Permian "red beds" of southern Okla-

homa rest upon upturned and bevelled Pennsylvanian and older rocks on the sides of the Arbuckle Mountains and on Ordovician and older rocks on the sides of the Wichita Mountains, but these unconformities do not extend over a few miles from the mountains. In north Texas careful stratigraphic and paleontologic studies fail to show any evidence of a stratigraphic break between the Pennsylvanian and Permian.

Orogenic movements which built the Ouachita, Arbuckle, and Wichita mountains began in Mississippian time. It has been shown elsewhere[1] that in order to account for the conditions proven by fossil evidence to exist at Healdton, one of the principal mountain-building movements must have taken place at that time. Following the deposition of the thick shale deposits of the Pennsylvanian a second, much less pronounced folding took place in the Arbuckle Mountains, tilting the Pennsylvanian sediments against the mountains, but not having any appreciable effect on the sediments over 5 miles away from them. During Permian deposition sandstones and shales of red, white, green, and yellow color were laid conformably or disconformably on the undisturbed Pennsylvanian blue shales and sandstones away from the mountains and unconformably over the already truncated blue shales on the flanks of the mountains.

With the isostatic readjustments following Permian deposition a gravitative settling of the younger sediments together with the resistance of the massives and smaller ridges which had risen in the Mississippian diastrophism developed a series of wave-like folds in the Pennsylvanian and Permian sediments parallel to and dependent on the axes, the size, and the arrangement of the older mountain masses, some of which were buried beneath the younger rocks. Of the buried masses the Criner Hills have since emerged, but the summits of the "Healdton Hills"[2] still remain buried at a depth of 875 feet or more.

Anticlines were developed, during folding, over the summits

[1] S. Powers, "Age of the Oil in Southern Oklahoma Fields," *Trans. Amer. Inst. Min. Engrs.*, 1918. In press.

[2] A term for the buried hills composed of Ordovician strata beneath the Healdton field.

of buried hills; other anticlines were formed at definite intervals between these hills and the larger mountains. Following the trend of the Arbuckle and Wichita mountains, lines of folding were probably developed around the mountains. Farther away from the mountains the lines developed a bow-like form, the center of the bow being between the mountains. South of the Arbuckle Mountains the Wheeler-Fox and Healdton-Loco fields have been developed along parallel lines, the axis of the latter line being on the top of the buried Healdton Hills. Between the Healdton Hills and the Arbuckle Mountains there is a broad synclinal trough in which the Fox anticline and small Graham fold have been developed at distances of 7½ and 13 miles, respectively, from the Healdton uplift, the Graham fold being only 5 miles from the unconformity at the Arbuckle Mountains (Fig. 29). On the summits of the anticlines the thicknesses of the beds

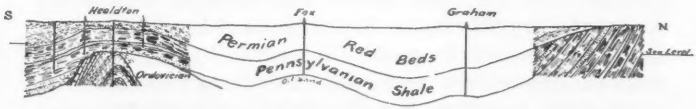


FIG. 29. Cross-section of the Healdton, Fox, and Graham anticlines showing the Pennsylvania-Ordovician unconformity beneath the Healdton field and the Permian-Pennsylvanian unconformity at the edge of the Arbuckle Mountains on the north. Vertical scale 4 × horizontal; total length of section 21 miles.

recorded in well logs are: Healdton 150–450 feet, Fox 1,000 feet, Graham 1,600 feet.

South of the Healdton field a broad synclinal trough, deepening to the west, extends between Healdton and Petrolia. In north Texas the prevailing dip is north, while in southern Oklahoma for some distance south of the Healdton anticline, the prevailing dip is south to southwest. The alignment of the Petrolia, Burkburnett, and Electra fields shows a curve parallel to the arrangement of folds north of the synclinal trough. The depth of the trough is unknown, but the known depth of the Permian on the south side, at Petrolia, is 1,200 feet or less, on the north side, at Healdton, 500 feet or less. Production of petroleum has

this far been obtained from only one locality, at Walter, in this synclinal trough owing to the difficulty of locating anticlines beneath the loose Cretaceous sand on the east and in the rolling prairies, underlain by Permian shale, on the west.

HEALDTON STRUCTURE.

Wegemann and Heald, in their structure-contour map of the Healdton field as it was in 1914,[3] show a large uplift, on which are superimposed a number of small domes. Production is obtained both from the smaller structures and from the saddles between them, but the largest production is from the summits of the small domes.

Since 1914 the expansion of the field to the northwest and southeast has opened new territory of as large extent as the proven territory of that date. The field outlines an area of peculiar shape with three symmetrically-arranged lobes on the north and a dry-hole line on the south, which has thus far been only crossed a short distance. The central lobe on the north is much the larger of the three. Tests now being made will show whether or not production is to be obtained between the central and eastern lobes.

Petroleum sands have been found to underlie the entire field at depths of 750 to 1,150 feet with the exception of the eastern end of the Southeast Extension. These shallow sands, from which black oil of gravity 25 to 31 degrees Baumé is produced, are known as the Healdton sands. Deeper tests in the Southeast Extension have opened lower sands at depths of 1,150 to 1,860 feet, of which the Simpson and Jackson sands in Section 15 and the Pugh sand in Section 18 are among the best known. Wells drilled through the Healdton sand in the center of the field show massive limestone and shale with no petroleum sands, and wells drilled through the deeper sands of the Southeast Extension in Sections 15 and 16 have found either thick limestone or limestone and shale with no indication of petroleum. Re-

[3] U. S. Geol. Surv., Bull. 621 *B*, 1915, Plate 3; see also J. H. Gardner, "The Oil Pools of Southern Oklahoma and North Texas," Econ. Geol., Vol. 10, 1915, pp. 422–434, and Okla. Geol. Surv., Bull. 19, pt. II., 1917, pp. 79.

cently a 1930-foot sand has been found in Section 25 and a 2716-foot sand found in Section 4.

It was the good fortune of the writer to be present when one of the wells, drilled a short distance through the Simpson sand in Section 15 was "shot" and to collect ejected blocks of fossiliferous Ordovician limestone from beneath it. Other collections of cuttings and large specimens have yielded Ordovician and Pennsylvanian fossils elsewhere described[4] as well as crossbedded green shale and yellowish sandstone which closely resemble the Permian rocks on the surface.

Stratigraphically, the rocks underlying the Healdton field comprise:

1. Permian sandstone and shale recorded as "red rock" and "water sand" in well logs although the exposures on the surface show pale greenish and yellowish sandstone; thickness 150–450 feet.

2. Pennsylvanian (?) blue shale, occasionally with water, oil, or gas sands and "lime shells"; water sands (basal Permian?) most frequent near the top of the shale; thickness 350–450 feet.

3. Pennsylvanian Healdton oil and gas sands, from two to five in number, without definite base, and with interbedded blue shale; thickness 200–400 feet.

4. Pennsylvanian blue or sandy shale with oil, gas, and water sands and frequently thin limestone beds; a water sand commonly occurring above the petroleum sands; thickness depends on depth of buried Healdton Hills.

5. Ordovician limestones and shales of the buried Healdton Hills, correlated with the Simpson formation[5] of the Arbuckle Mountains; without water or petroleum-bearing sands; probably steeply inclined; depth 1,200 feet or more below surface in Southeast Extension, possibly only 800 feet in a portion of Section 5.

[4] S. Powers, "Ordovician Strata beneath the Healdton Oil Field, Southern Oklahoma," *Bull. Geol. Soc. Amer.*, Vol. 28, 1917, p. 159; "Age of the Oil in Southern Oklahoma Fields." Trans. Amer. Inst. Min. Eng., 1918. In press.

[5] The Simpson formation (Ordovician) is not to be confused with the Simpson sand (Pennsylvanian).

Uncertainty prevails at the present time concerning the age of the blue shales and of the underlying Healdton sands. Fossils are absent from the Permian and no Pennsylvanian fossils have as yet been found above a depth of 1,000 feet. In the sections near the Arbuckle Mountains showing basal Permian, pale yellowish to greenish sandstones and shales occur below the red shales and sandstone. The thickness of this horizon is unknown and it may represent only the red rock recorded in Healdton well logs. Bituminous sands are found on the surface within 75 feet of the base of the Permian as well as at many other horizons, indicating that oil and gas sands of Permian age should be found at Healdton in the "red beds" just as at Wheeler. It has been concluded however, because of the blue color and varying thickness of the shale, that the so-called blue shale and the Healdton sands are both of Pennsylvanian age.

Pennsylvanian fossils prove that the following sands are of that age: the Simpson, which contains a green oil of gravity 31–32.5 degrees Baumé in Sction 15; the Jackson sand, which, although below the Simpson sand, contains a black oil of heavier consistency in Section 15; the 1,400-foot sand producing in the southeast corner of Section 15 and in the southwest corner of Section 16 and present in the adjoining portion of Section 14; and the Pugh sand in Section 18, T4S, R2W, at a depth of 1,860 feet. The first two of these sands are found directly above an Ordovician fossiliferous limestone ridge, which runs in a northwest-southeast line through the center of Section 15. The 1,400-foot sand is found on the south side of this ridge, the Pugh sand on the eastern end of the ridge, where it is much farther below the surface than in Section 15. Corresponding to the Pugh sand, but at the southeastern end of the field, the Roxanna Petroleum Co. has found a sand from 1930 to 1947 feet.

Ordovician fossils prove the Dunlap sand of the Bullhead Oil Co., A. Daney No. 14, in Section 4, T4S, R3W, depth 2716 to 2749 feet to be of Ordovician age. This is the first Ordovician oil to be produced in Oklahoma. The well was drilled to a depth of over 3,450 feet and then the 2716-foot sand was shot

twice. An initial production of 48 barrels resulted, but it is doubtful if this will be maintained or if other wells will find the same sand. The Gates Oil Co., drilling in a syncline in the Permian rocks in Section 14, is reported to have passed through a saltwater sand at 2,755 feet, undoubtedly an Ordovician sand. The high gravity of the oil in the Ordovician strata may be explained as a partly refined Ordovician oil similar to the bituminous sands of the same age in the Arbuckle Mountains, rather than as oil which migrated downward through massive limestones from the overlying Pennsylvanian sands. Oil of as high and also of higher grade was found in folded rocks of pre-Cretaceous age in the Ardmill well near Oakland, Marshall County.

Well logs report a variable number of Healdton sands and a variable thickness of individual sands, indicating that at least part of them occur as lenses. It is extremely difficult to correlate these sands except in adjacent wells. In the Northwest Extension, in Sections 30 and 31, T3S, R3W, the half-dozen sands farther south appear to merge into a single sand, whose thickness is about 100 feet. Few dry holes are found in the center of the fields in the Healdton sands, but one dry hole is located in the highest stratigraphic portion of the field, as mapped by Wegemann. This well, Sinclair-Gulf Oil Company, Million & Thomas No. 7, Section 5, found 524 feet of solid (Ordovician?) limestone, the top of which was encountered at a depth of only 800 feet.

Deeper sands of proven Pennsylvanian age are known in Sections 14–15–16–22–23, T4S, R3W, and in Sections 18–19, T4S, R2W. A deep test by the Bullhead Oil Company A. Daney No. 14, Section 4, T4S, R3W, now over 3,450 feet deep, failed to find any Pennsylvanian sand and instead ran into Ordovician limestone. The possibility of deeper sands northwest of Sections 4 and 5 has not been thoroughly tested. Similarly the north and south sides are probably underlain by oil sands at greater depths than at present thought. Deeper production may be expected until a heavy limestone of Ordovician age is found. All pure

white limestones are not, however, of Ordovician age, as is shown by Pennsylvanian limestone cuttings from Southwestern Petroleum Company, Hartgrove No. 1, in 19, T4S, R2W, depth 1,960–2,055 feet.

The Ordovician Healdton Hills may well be compared with the Criner Hills[6] of today. As in the Arbuckle Mountains, the Simpson formation shows interbedded greenish shales and sandstones as well as heavy limestones. High points at Healdton thus far proven occur in Sections 4–5 (800 feet deep) and in 15–16 (1,200–1,350 feet deep). Logs of offset wells show remarkable dissimilarities, as has been checked by examination of the cuttings. Incorrect logs, however, must be guarded against, as the bluish-white mottled limestone, in which some of the Ordovician fossils have been found, is frequently called sandy shale or white shale by the drillers. Sections of solid limestone over 300 feet in thickness have been found below producing sands in several wells: Sinclair-Gulf, Million & Thomas, No. 7, Section 5, 528 feet; Producers, Jerome Watson No. 11, Section 15, 568 feet (with Ordovician fossils); Gates, Jackson No. 13, same section, 347 feet, part of which is recorded as white shale.

The variation in logs of adjacent wells and the scarcity of either water or petroleum sands in the Ordovician strata indicate that these strata are dipping at high angles, probably to the south. Nothing can be said concerning the structure of the north side of the Hills as no deep wells have been drilled on that side. It is a general rule where unconformities exist in folded regions to find superimposed anticlines, the more closely folded structures being below, but as the Criner Hills structurally compose parts of several folds broken by faults, it is probable that the Healdton Hills represent a more complicated structure than a single anticline.

Topographic outlines of the Healdton Hills are suggested in several places. High points in Sections 4–5 and 15–16 and a low point in 18–19, T4S, R2W, have been described above. In

[6] J. A. Taff, "Geology of the Arbuckle and Wichita Mountains," U. S. Geol. Surv., Prof. Paper 31, 1904, pp. 47–50, describes the geology of the Criner Hills.

the southeast quarter of Section 15, production from a Pennsylvanian 1,400-foot sand in Producers Oil Co., Jerome Watson No. 12, and Ohio Cities Gas Co., Jerry McCoy No. 15, only ¼ mile south of the massive limestone in Producers Oil Co., Jerome Watson No. 11, indicates a dip of the topographic surface of the hills of over 9 degrees in that direction. Toward the east, between Sections 15, T4S, R3W, and 18–19, T4S, R2W, there is a dip of over 5 degrees in the buried topography. Between the Sinclair-Gulf, Million & Thomas wells on the south line of Section 5 and the Ardhoma Oil Co. well near the center of the west line of Section 8, the topographic surface dips at an angle of over 14 degrees.

Attention has been called to the straight line bounding production on the south. Whether or not this line is crossed farther than at present by future development, it cannot be explained as a fault because a few producing wells are found south of the line, and because the sands of the field extend past the limits of production, dipping steeply south. On this line some of the sands are dry, others contain a small amount of oil, which is sometimes heavy and asphaltic, while still others, especially farther south, have a large quantity of salt water. The straight line may be explained as the effect of buried topography on the development of the anticline in Pennsylvanian and Permian strata. If there was a sharp and straight ridge on the south side of the Healdton Hills in Pennsylvanian time similar to the ridges which bound the Arbuckle Mountains on the south and the Criner Hills on the west in Carter County,[7] with a still higher ridge behind the first, as shown in Fig. 2, it is possible to explain the sudden dip of the rocks on a straight line separating production and dry holes. Domes of considerable height and lateral extent in the younger sediments should slightly cross the line.

CHARACTER OF THE OIL.

Healdton oil in contrast to that found in the other large Oklahoma fields has an asphaltic base. It also differs from the other oils in the small percentage of distillates and hence is not

[7] U. S. Geol. Surv., Topographic Atlas, Ardmore Quadrangle.

valued as highly as Kansas and north-central Oklahoma oils. Little gas is produced from Healdton and casing-head gasoline plants have only recently been built. Most of the wells which came in as gas wells are now producing oil, and whatever gas comes with the oil is burned in flambeaus. A map of the field showing the wells which originally were gassers indicates that these wells are on the crests of the subsidiary domes on the Healdton anticline and if complete data were at hand it might be possible to show a relation of these gas wells to the highest ridge of the Healdton Hills.

Gravity determinations of the oil in some of the wells are given below, the figures being in degrees Baumé. For comparison the gravity of oil in other southern Oklahoma fields is given:

HEALDTON (PENNSYLVANIAN).

Owner.	Farm.	Location S-T-R.	Depth.	Gravity.
Thelma Oil Co.	Apple & Franklin	8–4–3	860	31.0
Hivick O. & G. Co.	Town lots	33–3–3	990	33.0
Bullhead Oil Co.	A. Daney (except No. 14)	4–4–3	1,000	31.2
S. & M. Oil Co.	Apple & Franklin	9–4–3	1,025	29.6
J. B. Shermerhorn	Fee	5–4–3	1,090	33.8
Humble-Gypsy	Staiti	32–3–3	1,190	29.3
Ohio Cities Gas Co.	J. McCoy	23–4–3	1,200	29.7
Westheimer & Daube	Fee	14–4–3	1,220	29.1
Dundee Pet. Co.	Westheimer & Daube	25–4–3	1,216	30.1
Magnolia Pet. Co.	H. Z. Ward	1–4–4	1,250	25.2
Hamon & Colcord	D. O. Coffey	15–4–3	1,250	32.5
Ruby Oil Co.	Ruby-Ingram	15–4–3	1,250	33.0
Gates Oil Co.	L. Carnes	22–4–3	1,273	32.1
Rockland Oil Co.	Sarasota	15–4–3	1,325	30.5
Carter Oil Co.	E. Pugh	18–4–2	1,860	29.0
Roxanna Reti Co.	Westheimer 3	25–4–3	1,930	35.0

HEALDTON (ORDOVICIAN).

Bullhead Oil Co.	A. Daney 14	4–4–3	2,716	44.6

FOX (PENNSYLVANIAN).

Gypsy Oil Co.	Mattie Morris 1	29–2–3	1 924	31.4
McMan-Magnolia	E. Hicker 1	20–2–3	1,960	34.0

GRAHAM (PERMIAN, PENNSYLVANIAN).

Van Winkle et al. (Perm.)	W. T. Pierce 2	18–2–2	1,656	19.0
Okla-Fox Oil Co. (Penn.)	Airington 1	7–2–2	2,635	20.0

MISCELLANEOUS.

Lonegrove field (Perm.), Amer. Ind. O. Co. Reed 1, Carter Co.	19–4–1	704	22–25
Wheeler field (Permian), Carter Co.	3–2	750	20–23
Loco field (Perm. & Penn.?), Stephens Co.	3–5	800	18–20
Arbuckle field (Cretaceous), Marshall Co.	25–5S–5E	400	47.0
Ardmill well (Pre-Cretaceous), Marshall Co.	17–5S–5E	1,785	63.0

The gravities of the Healdton wells when selected at random as in the above list do not prove any particular relation to depth, but a more complete list would show that the oil from the deeper sands is usually a better grade than is that from the shallower sands. A corresponding higher percentage of distillates in oils from deeper sands probably exists.

FUTURE DEVELOPMENT.

Dry holes are defining the limits of production of the Healdton field. Past experience has shown the danger of drawing these limits on the strength of an occasional dry hole, but a general survey of the field shows the structure dipping so rapidly at the present limits that it seems safe to say that while small productive domes may be located by drilling a few miles away from Healdton field and disconnected from it, and while deeper sands will certainly be found beneath part of the present Healdton field, and even slightly beyond the present limits of it, no important production can be expected from beyond the present dry hole boundaries.

With 1,740 producing wells, each well averaging approximately 36 barrels daily production, 42 wells drilling at a time and less than 10 abandoned each month, Healdton is nearing its maximum production, and the steady, comparatively rapid decline of the Oklahoma fields as contrasted to the Appalachian fields will not begin for another year. Much of the territory of the southeast extension, which is now producing from only the shallow Healdton sands, should produce from one or more deeper sands. Similarly, deeper tests should be made on the boundaries of the main field, especially in the Northwest Extension, to determine whether there are at that end of the field any deeper Pennsylvanian sands.

Ordovician rocks, when found in drilling, preclude the possibility of obtaining deeper Pennsylvania sands, but the chance of finding Ordovician sands still remains. In order to distinguish between Pennsylvanian and Ordovician limestones and shales, it is necessary to examine with a hand lens or microscope the cuttings from the wells. Ostracods characterize cuttings from Ordovician rocks, tubular bryozoan stems and crinoid segments characterize cuttings from the Pennsylvanian. One or two fossil fragments may usually be found in a handful of limestone cuttings.

Healdton emphasizes the importance of unconformities in petroleum geology. A hiatus of over 8,000 feet of sediments exists below the low anticline in Permian rocks at the surface and in Pennsylvanian rocks beneath the Permian. Along the line of unconformity and in the lenticular sands immediately above are found the most productive oil sands. It is a rule that buried structures such as the Healdton Hills are anticlines which are more steeply folded than the surface anticlines, but too few deep wells have been drilled at Healdton to prove or disprove a buried anticline. If the unconformity were not of such stratigraphic magnitude and if the folding in the underlying rocks were not as steep as it is supposed to be, production of great importance might be expected in the older rocks, but the facts presented above show the uncertainty of deep drilling at Healdton.

CLASSIFICATION OF ORE DEPOSITS BASED UPON ORIGIN, DEFORMATION, AND ENRICHMENT.

T. T. Quirke.

Mining engineers and geologists generally appreciate the importance of the deformation of ore deposits. The mining of ore is greatly impeded in many places by faulting, which displaces or cuts off entirely the ore shoot. On the other hand, many an ore body owes its values in profitable concentration to water circulation made possible by fault and fracture planes.

Subdivision upon the basis of origin, enrichment, and deformation brings about a certain grouping of ore deposits which is, in some ways, fortunate. The copper deposits of secondary enrichment fall naturally together, the gold deposits enriched at the surface are in one group, and the deposits enriched by gold precipitated from solution are likewise together. Thus, although the groups overlap one another, a classification on the basis of enrichment and deformation goes a good way towards a classification according to metals, with the advantage that deposits worked only for primary ores are separated from those exploited for secondary values. The accompanying diagram (Fig. 30) suggests that the enrichment of copper, silver, gold, and iron depends largely upon the presence of faults and fractures in the protore.[1]

The diagram includes a great circle which is divided into eight sectors, wherein the ore deposits are listed according to origin. There are two main concentric divisions, a double circle and a ring about it. Within the double circle is noted the manner of

[1] R. Beck, "The Nature of Ore Deposits," translation by W. H. Weed, New York, 1909, p. 392.

W. H. Emmons, "The Enrichment of Sulphide Ores," U. S. Geol. Surv., Bull. 529, 1913, pp. 26–30.

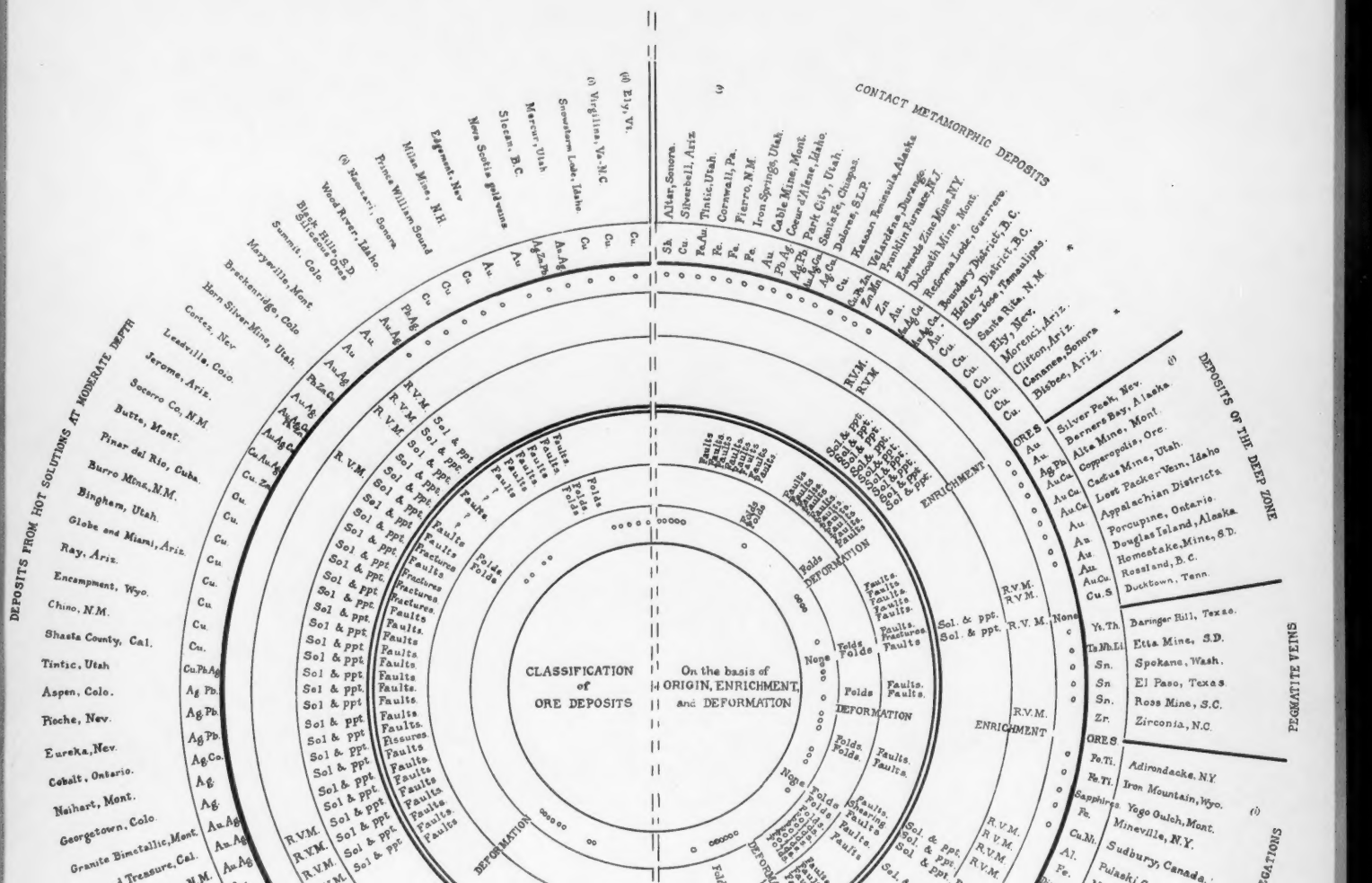
J. E. Spurr, "The Relation of Ore Deposits to Faulting," Econ. Geol., Vol. XI., 1916, pp. 601–622.

deformation of the ore body, upon the ring is stated the nature of enrichment. Deformation is classed as none, folding, faulting, and both folding and faulting. Enrichment is recorded as none, by removal of valueless materials (abbreviated on the diagram to "R. V. M."), and by solution and precipitation of the ore metal referred to, and by both processes.

In some cases there are several types of ore deposits in one district, which makes it necessary for any satisfactory classification to have flexibility. In the diagram presented, modification is made either by specifying the metals involved, or by listing the name of a particular mine instead of the name of the district. For instance, San Francisco district, Utah, is represented by the Cactus mine, a deposit of the deep zone, and by the Horn Silver mine, a deposit of moderate depth; the deposits of Tintic, Utah, are listed twice, once as gold and iron ores, and again as copper, lead and silver ores. Some deposits having actual but economically trivial enrichment are listed as not enriched. Primary ore deposits in glaciated regions, from which superficial enrichments have been removed in all probability, are classed as not enriched. Some of the iron ranges are listed as being enriched only by removal of valueless material, although there has been much iron precipitated as cement; this emphasizes the great importance of solution and precipitation processes in the case of the Marquette and Penokee-Gogebic ore deposits. In other iron deposits these processes are unimportant relatively.

Several deposits listed here as enriched and not deformed are probably shattered and fractured if not faulted. But this presentation pretends to be little more than a compilation of the published data available to the writer. In this study the most difficult data to ascertain have been the manner and degree of deformation of the ore deposits. In regard to several deposits no clear statement about the manner of deformation seems to have been published.

Objections to this scheme of presentation are that there is no indication as to whether deformation preceded or followed enrichment of the protore, or if there were several episodes of


CLASSIFICATION of ORE DEPOSITS
On the basis of ORIGIN, ENRICHMENT, and DEFORMATION
DEPOSITS FROM HOT SOLUTIONS AT MODERATE DEPTH
CONTACT METAMORPHIC DEPOSITS
DEPOSITS OF THE DEEP ZONE
PEGMATITE VEINS
ORES
ENRICHMENT
DEFORMATION
R.V.M.
Sol. & ppt.
Faults
Folds
None

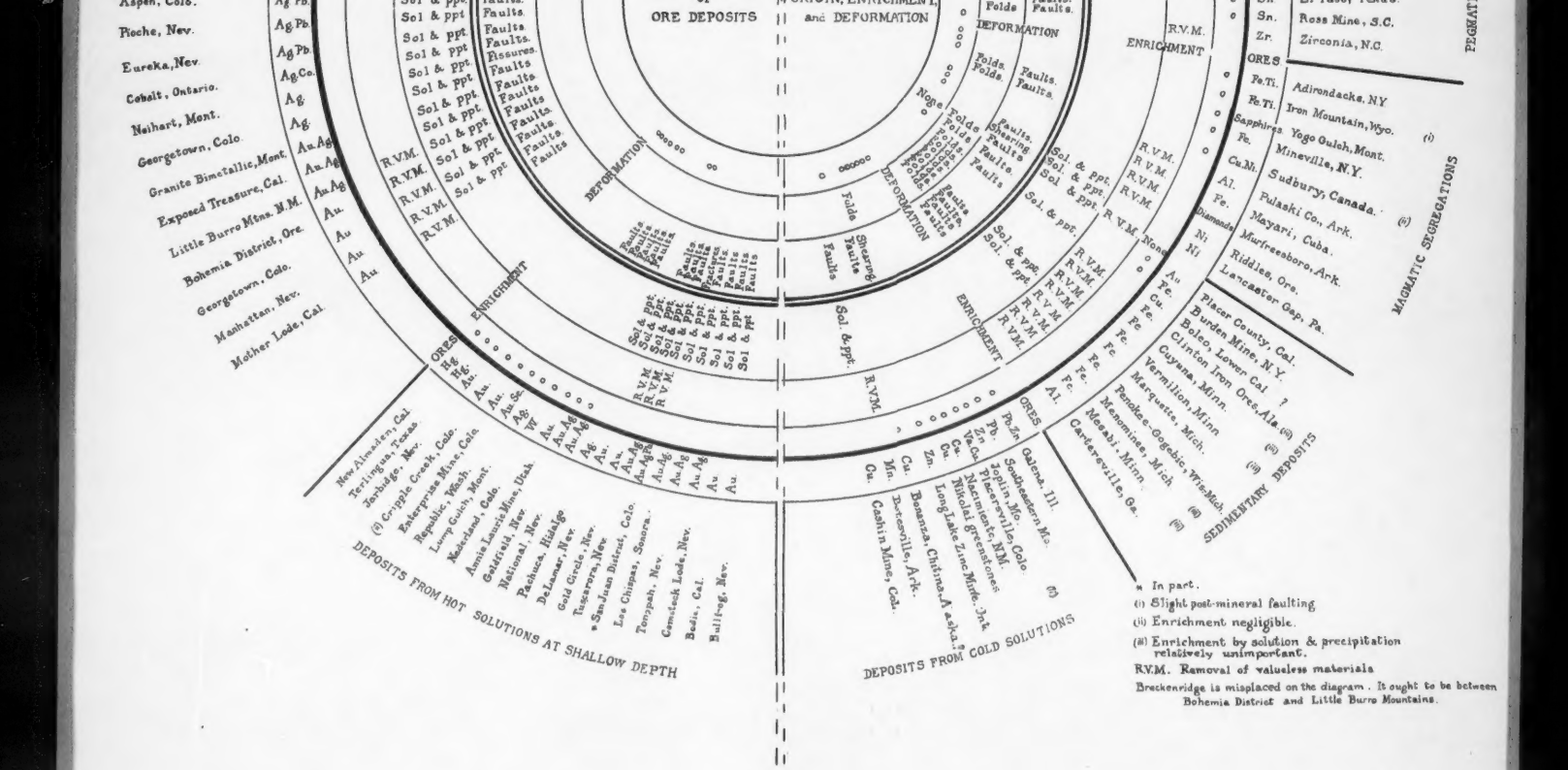

ORE DEPOSITS
and DEFORMATION, ENRICHMENT
DEFORMATION
ENRICHMENT
R.V.M.
Sol & ppt.
Folds
Faults
Shears
Joints
Nose
Sheeted Zone
ORES
Aspen, Colo.
Pioche, Nev.
Eureka, Nev.
Cobalt, Ontario.
Neihart, Mont.
Georgetown, Colo.
Granite Bimetallic, Mont.
Exposed Treasure, Cal.
Little Burro Mtns. N.M.
Bohemia District, Ore.
Georgetown, Colo.
Manhattan, Nev.
Mother Lode, Cal.
New Almaden, Cal.
Terlingua, Texas
Jerome, Nev.
(i) Cripple Creek, Colo.
Enterprise Mine, Colo.
Republic, Wash.
Lump Gulch, Mont.
Maitland, Colo.
Annie Laurie Mine, Utah
Goldfield, Nev.
National, Nev.
Pachuca, Hidalgo
Delamar, Nev.
Gold Circle, Nev.
Tuscarora, Nev.
* San Juan District, Colo.
Los Chispas, Sonora
Tonopah, Nev.
Comstock Lode, Nev.
Bodie, Cal.
Bullfrog, Nev.
DEPOSITS FROM HOT SOLUTIONS AT SHALLOW DEPTH
Galena, Ill.
Southeastern Mo.
Joplin, Mo.
Platteville, Colo.
Placerville, N.M.
Nikolai greenstones
Macmillan, Ark.
Long Lake Zinc Mine, Ark.
Bonanza, Chisna, Alaska
Batesville, Ark.
Cashin Mine, Colo.
DEPOSITS FROM COLD SOLUTIONS
Placer County, Cal.
Burden Mine, N.Y.
Bolso, Lower Cal.
Clinton Iron Ores, Ala.
Cuyuna, Minn.
Vermilion, Minn.
Marquette, Mich.
Penokee-Gogebic, Wis.-Mich.
Menominee, Mich.
Mesabi, Minn.
Cartersville, Ga.
SEDIMENTARY DEPOSITS
Adirondacks, N.Y.
Iron Mountain, Wyo.
Yogo Gulch, Mont.
Mineville, N.Y.
Sudbury, Canada.
Pulaski Co., Ark.
Mayari, Cuba.
Murfreesboro, Ark.
Riddles, Ore.
Lancaster Gap, Pa.
Ross Mine, S.C.
Zirconia, N.C.
MAGMATIC SEGREGATIONS
* In part.
(i) Slight post-mineral faulting
(ii) Enrichment negligible.
(iii) Enrichment by solution & precipitation relatively unimportant.
R.V.M. Removal of valueless materials
Breckenridge is misplaced on the diagram. It ought to be between Bohemia District and Little Burro Mountains.

FIG. 30.

deformation. It does not state whether or not deformation was germane to ore enrichment.[2] In spite of these faults, it is hoped that the diagram may be useful. It presents in a compact form a classification of most of the well-known ore deposits of North America. It shows the general origin of all the chief metals. It illustrates the well-known fact that copper, silver, and gold (in the presence of manganese) are enriched commonly by solution and precipitation, and that gold, aluminum, iron, and precious stones are likely to be found in some variety of residual enrichment. It suggests that, in general, deposits not deformed are not enriched beneath the surface, and, provided minerals susceptible to solution in oxidizing waters are present, that deposits deformed are in most cases deposits enriched.

This diagram was intended chiefly as an aid in the teaching of economic geology. It was prompted by the desire to have some form on which students could plot the characteristics of any ore deposit so as to show its relation to other ore deposits. Any ore deposit may be listed outside the circles, opposite that sector which denotes its origin, and then, on a line drawn from the name of the ore deposit to the center of the circles, suitable marks may be made to indicate which rings denote its manner of deformation and the nature of its enrichment. This study was suggested by the manuscript of a book on ore deposits now in press, written by Dr. W. H. Emmons.[3]

[2] Out of 140 ore deposits listed, apparently 30 are not affected by faults. Of the remaining 110 deposits, 70 were localized by faults, 30 are faulted but not enriched, 56 are faulted and enriched, and 9 were faulted after enrichment. In several cases faulting and secondary enrichments have been repetitive. Fifty-six deposits are enriched by solution and precipitation, out of which 47 are known to be faulted.

[3] "Principles of Economic Geology." The McGraw-Hill Publishing Co., New York.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE ABSENCE OF WATER IN CERTAIN SAND-STONES OF THE APPALACHIAN OIL FIELDS.

Sir:—Under the above heading Frank Reeves[1] discusses a subject which has seemed to me in great need of attention, both as to discussion of available data and gathering of new data, and he formulates a new hypothesis—connate dryness—to account for the generally reported lack of water in certain deep sands. The illustrations in the paper are of especial interest and they, with other facts presented, add to the available information on the subject. In particular the distribution of certain sands often reported dry, though referred to in the form of generalizations to which exception may in places be taken, are noteworthy contributions. However, it seems to me that the new facts and generalizations presented, together with other considerations, are susceptible of a different interpretation from that placed upon them by Reeves. The dominant facts in the case are these: Many if not most deep wells in the Appalachian oil fields penetrate one or more sands that yield little or no water, oil or gas. Few, if any, formations show "dry" sands more generally than the Catskill. Most of the deep wells of the region are said to have penetrated one or more dry sands, and among drillers, operators,

[1] Reeves, Frank, "The Absence of Water in Certain Sandstones of the Appalachian Oil Fields," ECON. GEOL., Vol. XII., pp. 354-378, June, 1917.

geologists, and others there seems never to have been a question but that the pores of certain sandstones are in many places partly or wholly free from water, oil, or gas. The inference is in harmony with that drawn by miners of coal and metal ores, concerning the absence of water in deep workings.

The doubt concerning the validity of the general inference—the suspicion that most of the "dry" sands are really saturated with water that for some reason can not get out—arose after some years of discussion with Munn, during which time attempts were made to grasp the significance of the phenomenon and find the explanation. Rock samples were obtained from deep mines, a special examination of some thousands of well logs was made, and drillers and others were questioned. In particular it seems to me that the basis of Reeve's conclusions that the Catskill sands are really dry and have been dry from the beginning is scarcely sufficient and that it does not harmonize with certain principles of physics.

Reeves's arguments may be summarized as follows:

A. EVIDENCE OF THE ESSENTIAL DRYNESS OF DRY SANDS.

1. "Dryness" is more characteristic of certain formations than of great depth, as is shown by the finding of water-yielding sands near the bottoms of some of the deepest wells.

2. If the "dry" sands were saturated with water, gas pressure should drive it into wells. The "dry" sands yield oil and gas but not water.

3. In "dry" sands the oil pools are found in synclines.

B. EVIDENCE THAT SANDS HAVE BEEN DRY EVER SINCE THEY WERE BURIED.

4. There is a striking relation between dry sands and red beds believed to be continental; on the other hand marine formations generally yield much water. The Catskill strata are continental deposits and "dry" sands are characteristic of this formation.

5. Certain well-dried and air-filled sediments will not allow water to enter them.

6. There is no way in which connate water could have been driven out of Appalachian sandstones. The suggestions that hydration, consolidation, heat, expansion, evaporation or drainage might effect the result are inapplicable.

7. The red color of Catskill shales is thought to have resulted from oxidation after deposition, which could not have occurred if all beds were saturated.

These arguments will be considered in order, but first I would like to make the point that notwithstanding the multitude of wells drilled and the large number of logs kept, most of which have never been published, the data are, in view of the fact that they are not very harmonious, dishearteningly scant. Very deep wells—say over 5,000 feet—are not numerous and the amount of carefully collected and preserved data concerning materials penetrated in wells over 3,500 feet deep is not nearly so large as could be desired, especially since there are numerous exceptions to both general rules—that Catskill or continental sands are dry and that "dry" sands become more numerous with depth. In some deep wells many sands yield much water, and in others, as for example the Goff well near Clarksburg, W. Va., now 7,000 feet deep, very little water is yielded by any formation or stratum.

Relation of dryness to depth.—On page 363 Reeves says: "In considering the explanations of Munn[2] and Shaw, the fact need only be mentioned that water has been found below the Catskill sands in the two wells mentioned above to vitiate the force of their arguments as they are based chiefly on the factor of depth." I should say that instead of vitiating my

[2] Munn is, I think, somewhat misrepresented, for he does not state that "water is present in all sands." In fact, he does not seem to refer to the subject on page 26 of his Menifee-Ragland report, and on page 24 of this report he grants by implication the reality of partly dry sands, saying: "The critical attitude of an oil sand seems to depend on its content of water . . ." and ". . . the water content of a given sand may change materially with the lapse of geologic time." He does, however, make the double point concerning individual sands that it is "not safe to assume because a given 'sand' shows no water in wells surrounding an oil or gas pool in it, that this sand contains no water and that the pool was not accumulated by moving water."

suggestion it is, on the contrary, quite in harmony with it. If the "dry" sands contain water which can not get out because it is in lenses of sand that are effectively sealed, the number of such sands should increase *irregularly* with depth, and a sand 6,000 feet below the surface may be less well sealed and may yield more water than one 3,000 feet below. As has been known for many years water is yielded by certain sands lying at depths greater than 2,500 or 3,000 feet in the Appalachian fields and elsewhere, and dry sands are often reported from shallower depths. The general inference that dry sands seem to become more numerous with depth is still to be explained.

Even if the reports of dry sands were known to be correct, there would still be some room for debate as to whether dryness is a function of depth or paleogeography; well logs and general testimony indicate that the quantity of water or the number of water-yielding sands does not decrease regularly with depth, neither are such sands altogether, if indeed as a rule, wanting in continental deposits or those containing red beds. The fact that sands lying far below the surface often yield water in Pennsylvania, California, Oklahoma, and elsewhere, is adduced to show that dryness is not a function of depth. But this does not disprove the generalization that dry sands become on the whole more numerous with depth. If California sands seem exceptionally wet, perhaps it is because dips are steep and outcrops of deep sands and connecting beds relatively near. As a matter of fact, dry sands are commonly reported in California.

Force Driving Water into Wells.—Reeves says: "The fallacy of these explanations [those of Munn and Shaw] is also apparent when it is pointed out that the impelling force which generally drives water into the well is gas pressure and not the force resulting from hydraulic movement or the hydrostatic head of the water" (p. 363). This brings up considerations that must be borne in mind, though it is believed that they do not prove that "dry" sands are dry or even lend strong support to such an inference. If a continuous or persistent layer of fairly clean sandstone contains, in places, gas pools under high pressure and be-

tween the gas pools fails to yield any water, oil, or gas, the inference that the sand has empty pores might at first seem well warranted, for if it contained one of these fluids the gas should, through expanding, force it into the well. On further consideration it is seen that the inference of dryness does not necessarily follow, and the failure of a deep sand to yield or absorb anything really points in another direction, namely, that the pore contents can not get out, particularly if the same apparently continuous sand contains elsewhere water, oil, or gas under pressure.

I can not grant that gas pressure and not water head is the impelling force in driving water into wells, else departures from the hydrostatic pressure would be general and great. Gas communicates hydrostatic and other pressures and increases the rate of yield by reducing, in effect, the friction involved in the movement of water through tortuous channels of minute diameter and great length. Incidentally gas pressure commonly leads of course to some reduction of pressure as it expands, because, having lower viscosity, and larger channels, it flows with less friction than the water that tends to follow it up. As a matter of fact the pressures in gas fields are, as a rule, not very far from the pressure that would be exerted by a water column extending to the surface, and it seems most reasonable to assume that though a gas pool may increase the flow of water into a nearby well by reducing the amount of moving water, the initial closed pressure on gas, water, and oil is, for the most part, due to the weight of a column of water extending to the surface at the outcrop of the sand or some connecting stratum, except as modified by hydraulic gradients to intermediate producing wells. No doubt chemical changes and perhaps other causes may develop pressures considerably above or below the hydrostatic head of a column of water extending to the surface. Absolute imperviousness of surrounding material would not be necessary for this, because, through capillarity, water-soaked material around a pool may be effectively impervious and because movement through clays and shales being slow, the pressure might grow or decline more rapidly than it could be equalized.

Other opposing considerations seem to overbalance entirely the apparent implication of the fact that gas pressure, hydrostatic head, capillarity, pressure from below or that developed from within by chemical reactions, are not sufficient to force a perceptible amount of fluid out of the "dry" sands. The question as to what the pores contain if they lack water, oil, or gas, is one which rises insistently, and if the pores are empty or contain some fluid under one atmosphere of pressure and yet are continuous over broad areas in some parts of which gas, oil and water are found under high pressure, why do not the fluids move so as to equalize the pressure? The inference seems unavoidable that the appearance of continuity in the sand is deceptive and that the gas, oil and water in areas where they flow into wells are shut off from other or so-called dry portions of the sand by some kind of barriers.

Reeves's papers, like many other papers and reports, state that a persistent and deep-lying sandstone may have empty, or nearly empty, pores throughout a broad region except that in numerous irregularly scattered places it contains and is ready to yield oil. In accordance with this is the common inference that as a rule a stratum that yields no oil really contains none. I have often wondered if this is really true, and if it may not be that some of the reported dry sands, whether shot or not, are actually oil-bearing though not oil-yielding at the particular places where penetrated and reported dry. Of course a very small yield of oil is more likely to be noted than a very small yield of water especially in localities where it is the practise to test drillings from possible oil bearing sands in hot water.

Although, as Reeves says, there is not much more reason for assuming that the "dry" sands are filled with water than that they are filled with oil, there may be some basis for such an assumption, for possibly they differ in more or less essential respects from those sands that yield water and oil. On the other hand, if the "dry" sands contain gas, whatever the nature of the grains and the shapes of the pores, provided only that they are inter-connecting, they should yield some of it to the wells, because of the expansive property of the gas.

The suggestion persists that most of the so-called dry sands may contain water or oil, though because of consistent and abundant contrary testimony it has for several years seemed unwise to trouble the petroleum world with the query until it could be shown to be well founded. It seems even possible that gas may occupy the pores of some of the portions of sandstone layers reported to be dry, because the rock has small or closed pores[3] cemented or clogged by silica, clay, bitumen, or some other substance so that almost no gas can escape.

It may be argued that if many "dry" sands are in reality water-soaked but sealed-in sands with large communicating pores, then in cases where the top of drilling water gets below them before they are cased off, air should enter the upper part of the sand while water flows out from the lower part. It seems possible, however, that capillary forces might prevent such a movement. In any case since it has been shown that first-class oil and gas sands have been reported at first as dry, particularly in wells drilled with a rotary, and that large gas wells can be killed by filling them with water, it should lead to caution in generalizations concerning "dry" sands.

It may be inquired does this mean an immense amount of unrecoverable oil in the Catskill? The logs of thousands of wells that have penetrated one or more of its sands indicate that certain areas for each sand are dry, other areas oil- or gas-bearing, and others water-bearing. Is it to be assumed not only that the "dry" areas are not dry, but that the ratio between the extent of the water-bearing and the oil- and gas-bearing areas is similar in the "dry" territory to the ratio between such areas in the "non-dry" territory? No, because differences in intermolecular attractions and perhaps other factors tend to drive oil and gas into places where the pores are largest, and in such places, as a rule, water, oil, and gas flow most readily into wells.

[3] It should be remembered that the average size of grains in a sand may be large, while the pore diameters are small; that pore size depends largely on range in size of grain, and amount and nature of cementation, that when a rock is said to be porous it is meant that it has large pores and not much pore space.

It is contended that Johnson's suggestion that water may be driven from a sand while oil is left behind because of its greater viscosity is inapplicable because "under the pressures that would bring this about the materials would have the same viscosity and surface tension" (p. 365). In reply it may be argued that this statement is inharmonious with remarks concerning the greater viscosity of oil on pp. 363 and 378; that little seems to be known concerning the effect of pressure or viscosity of fluids;[4] that presumably water and oil would have the same viscosity at only one pressure, whereas in oil fields we have to deal with a wide range of pressures; and that the pressure that would bring movement about is not an absolute but a differential pressure. Much also must be taken into consideration before drawing conclusions as to the effects of surface tension. Whether the variations in temperature from point to point in the strata within a mile or two of the earth's surface, though not great, affect the viscosity of water and oil more than the variations in pressure which, as has been pointed out, are great, I do not know. Increase of temperature evidently has a greater effect on the viscosity of oil than on the viscosity of water and we should think of both oil and water in the earth as having a rather wide range in viscosity. Under some conditions one is more viscous and perhaps under other common conditions, the other. Which excels, would depend upon several factors such as nature of the oil, temperature, and pressure. Moreover, if the "dry" sand conception is correct, the great difference between the pressure in the pores of the "dry" sands and that in the pores of other portions of the same bed, and in other beds, would almost certainly lead to migration and equalization of pressure through solution. Oil and gas are both to a certain extent soluble in water and the principles of physical chemistry would seem to demand that at points of greater pressure more would be dissolved, and the oil and gas would thus migrate to points of less pressure. Apparently oil

[4] Most treatises and collections of physical tables do not mention it, but Poynting and Thomson on page 217 of their "Properties of Matter" 4th ed., 1907, state that the "viscosity of water diminishes slightly under increased pressure, while that of benzol and ether increases."

and gas may thus be transferred through water. The process would be slow, if all fluids were quiescent, but the time is abundant.

Synclinal Oil Pools.—Reeves describes the structural position of oil and gas pools in sands partly filled with water as being between synclinal and anticlinal, and in "dry sands" as being synclinal. He refers in several places to this relationship. Most if not all other geologists who have given attention to the Appalachian oil fields now have the same conception. The inference seems to be regarded as so well founded and generally known that there is no need of referring to those who formulated it. It seems to have originated with Griswold and Munn, who discussed it in Bulletin No. 318 of the United States Geological Survey.

On page 59 of his Johns Hopkins paper[5] Reeves says concerning the Appalachian oil fields "the most common condition encountered is where there is but sufficient water to fill up the synclines. . . . In sands that contain no water the oil is found in synclines" and "in general it may be stated that the Pennsylvanian sands are saturated, the Mississippian sands semi-saturated and the Catskill sands dry." In his ECONOMIC GEOLOGY paper he says on page 359: "where there is no water in the sands the oil usually occupies the synclinal areas;" on page 363: ". . . the oil pools in the sands of the Catskill formation usually occur in the synclines," and on page 372: "with these exceptions the sands [Catskill] to all appearances are dry. This is verified by the fact that the oil almost invariably occurs in the synclines." Other similar statements almost without number might be quoted from the literature touching Appalachian oil-field geology and the conclusion thus carries a heavy weight of general testimony. Although Reeves readily assumes that water and oil in a partly filled sand will migrate toward the bottoms of synclines and take positions according to their specific gravities, he does not believe that water would penetrate this same dry sand. It would seem

[5] Reeves, Frank, Origin of the natural brines of oil fields: Johns Hopkins Univ., Circ., New Ser., No. 3, pp. 57–68 [255–266], 1917.

that water and oil must penetrate it and migrate through it in order to reach the synclines or any other structural features, and yet it is assumed that the dry portions of a sand are dry because water has not been able to enter them in all the long periods of geologic time since their deposition.

But consider this conclusion in connection with some well-known facts. To put it in Reeves's words "throughout all southwestern Pennsylvania and northern West Virginia these sands [Catskill] have been penetrated by the drill . . . and thousands of wells have tested the synclines as well as the anticlines, with the result that oil and gas have been found in numerous localities. Many of the oil wells have been of the gusher type, that is, oil is forced out of the wells by gas pressure, which occurs in the sand back of the oil, and yet with the exception of two local areas no water has appeared. This coupled with the fact that the oil occupies the syncline makes it appear as a proven fact that these sands contain no free water" (pp. 363–364).

Thus the oil and gas of the Catskill and other sands locally or generally reported dry show considerable pressure, for they enter the wells and rise to a greater or less height above the bottom, often flowing out at the surface, indicating pressures of scores and, in some of the deeper sands, more than a hundred atmospheres. Hence the inference concerning the existence of dry sands, which may almost be spoken of as universal, requires that although in places the sand contains oil and gas under pressures ranging up to many hundred pounds to the square inch, in other places as far below the surface the same continuous sand has no water, oil, or gas in its pores and yet when penetrated air or water neither rushes into or out of the well to or from the sand. Is it within the bounds of reason to assume that air-dried sands may become, and have become, buried under thousands of feet of water-soaked or largely water-soaked strata with no increase in the pressure on the fossil air in the pores of the sand? Moreover, would not the inert element nitrogen common in the gas of some other regions be found in large amounts in the gas and perhaps oil of such sands?

The conclusion seems unavoidable that the sand where reported dry is in some way shut off from portions that yield water oil or gas, and if so shut off it may actually contain water or possibly oil and fail to yield any considerable quantity to a well. As a matter of fact, as Reeves himself notes, the Catskill sands are both thinner and less persistent than the overlying Mississippian sands. There are thus three factors each of which would in the West Virginia fields tend to give a greater appearance of dryness to the Catskill sands as compared with those of the Mississippian, because through involving greater friction in movement they would hinder the egress of water: (1) greater depth, (2) thinner sands, and (3) less persistent sands.

Relation between Continental Deposits and "Dry" Sands.—The Catskill is described as a continental deposit—"a non-marine facies of the Upper Devonian"[6]—and scarcity of water in its sands is contrasted with the abundance of water in sands occurring in marine formations in many parts of the world. It is recognized, however, that a sea lay to the west and frequently flooded the western part of the Catskill area. It is said that the "sands are dry to the east where all the facts indicate subaërial deposits."[7] However, it can be shown that, at times at least, the sea extended to the eastern margin of the basin. Butts[8] has collected Catskill marine fossils at several localities along the Allegheny front and he also found a marine fossil in red beds in Warren County, Pa. On the other hand, Fig. 12 of Reeves's paper shows, instead of close association of red beds and dry sands, that the areas of red beds are about the same as the "areas containing water." If "areas containing Red Beds" was intended to read "areas containing *no* Red Beds" it might be remarked that red beds do not seem to characterize the eastern part of the basin.

Water has been found in the Catskill in many wells, and dry sands are frequently reported in formations above and below.

[6] Reeves, Frank, Origin of the natural brines of oil fields, p. 59 [257].
[7] Econ. Geol., vol. 12, p. 373.
[8] Butts, Charles, oral communication.

Furthermore, according to reports, the Catskill sands, like others, are more frequently water-bearing where they lie within 1,500 feet of the surface than where they lie at greater depths.

Reeves's opening statement that "the petroleum-bearing sandstones of the Catskill . . . to all appearances contain no water" (p. 354), is somewhat too sweeping. In fact, water has been found in these sandstones in a good many wells, as Reeves indicates on a later page.

But even if it could be shown that "dry" sands are more common in continental deposits containing red beds than in others, the very real possibility would remain that such deposits have more lenticular, sealed-in, or otherwise peculiar sands than other formations have, and hence yield their water less readily.

Exclusion of Water by Air-dried Sands.—In support of his unique hypothesis that the dry sands became dry through exposure to the air and were sooner or later buried under water-filled sediments without imbibing water, Reeves cites testimony to the effect that "air-filled material will exclude water" (p. 366) and the results of experiments made with glass tubes two thirds filled with dry sands. Munn and I mixed sands with air, gas, oil, and water in various ways and watched their behavior in the search for light on the possibilities and probabilities of gravitational sorting. The results seemed to confirm Munn's earlier conclusion that motion of both water and oil is generally necessary to bring oil to the top of water and particularly to the tops of anticlines, though after a large pool of oil collected it might be buoyed up through a sand where a small body of oil would not.

Among other things it was found that in jars or tubes of dried sand over a centimeter in diameter water would readily sink to the bottom, whereas in tubes less than a millimeter the water would sometimes not migrate to the bottom in months. Various sands were used and some loess which is essentially an extremely fine quartz sand with a small admixture of clay, the percentage being too small to clog the pores.

Our experience would thus not agree with that of Reeves, who found that in tubes of dry sand 30 centimeters (about a

foot) in diameter water would sink "only to a limited depth." However, there seems to be an error in his figures, for he says that the tubes were one half meter in length and the "water would in a few minutes saturate about 60 centimeters of the upper portion of the sand" (p. 366).

On the other hand, I do not fail to recognize that the behavior of the water would differ markedly according to several conditioning factors. The results would depend for one thing on how thoroughly the sand had been dried, on the sizes and shapes of the pores, on the mineral constitution of the sand as well as on the diameter of the tube. I would be surprised, however, to know that, as a rule, water would not displace air in the pores of an air-dried sand filling a tube 30 centimeters or even a tenth of that amount in diameter. The result depends to a considerable extent on whether or not the sand is kept covered with water or water-soaked loose material, in other words to what extent gravity is aided by capillary pull in the rearrangement.

But even though it were true that in a tube of large diameter containing sand and water under certain circumstances would not penetrate the sand readily, and even though in a semi-arid region water falling on the surface of the earth may be slow to penetrate the thoroughly dried soil, it seems to me that physical principles and matters of everyday experience throw very great doubt on the inference that sands underlying broad areas though buried under and between sediments filled with water have remained dry throughout the long ages of geologic time.

To be sure, intermolecular attractions might operate to hold water in a shale or clay with great tenacity and for a considerable period of time, particularly for a small area, but where thousands of square miles and millions of years are involved, during which time there have been compacting, uplifts, tidal kneading, changes in air pressure and in underground temperature, and numerous other factors tending to make underground fluids move about, it would seem quite beyond reason that any layer with large connecting pores should remain dry.

Drying of Sands after Burial.—Even though truly dry sands

occurred promiscuously at all depths, or were characteristic of certain formations, neither of which I believe to be true, would it follow that the dry sands were originally dry? May not some layers of sand have been drained, while others above and below were not? Relatively impervious layers may be so arranged around a sand as to practically block a flow that would otherwise take place, or the shale below a sand may be saucer-shaped and in such an attitude as to prevent water from draining away to an otherwise unobstructed outlet. Such sands might thus remain wet while intermediate sands were drained.

Experience in various sedimentary basins and the study of recently deposited sands and muds has led me to the notion that the upward and outward movement of water on account of compacting as outlined by King and later by Johnson may not hold as a rule after emergence, particularly in the later history of the formations. The available facts seem to suggest that after the region rises above sea level the water of deposition is affected by two tendencies and that a downward movement is commonly if not usually the result. Compacting involves of course the driving out of water, and the easiest way is presumably at times upward, but gravity or the hydrostatic head pulls the water downward, though movement in that direction is opposed by the friction of movement through minute pored strata and commonly by capillarity. It is unsafe to assume that upward and outward movement is the rule, though the apparent high degree of imperviousness of certain beds inclosing oil and gas pools inclines one to such a view, for about the borders of such pools intermolecular attractions are apparently the dominating forces.

In the large present-day deltas of the world one sees at the surface instead of innumerable salt seepages and accumulations of salt, fresh or brackish water, with only occasional salt springs, indicating that the dominant movement is downward even from the beginning, and fresh water has penetrated deepest in the older or landward portions of the deltas. Present delta deposits may differ on the whole from Carboniferous delta or basin deposits, but it would not be difficult to find present deltas with the

essential features of porous layers and lenses inclosed in mud as fine-grained and impervious as Carboniferous shale. What chance would there have been of raising crops below sea level on the beds of drained polders in Holland and Belgium if the usual thing were upward movement of connate water on account of compacting?

It seems probable not only that compacting is too slow to play an important part, but that the main part of the compacting of a formation takes place early in its history and that after a relatively short time the process almost, though never quite, ceases (except on exposure to the weather).

In his other paper Reeves[9] disposes of the possibility of draining sands in the following words:

> Drainage in an area of the nature of the Allegheny coal basin is not possible since the basin is so shaped that the water cannot drain out of it. Moreover these sands are below sea level and hence not subject to drainage (p. 61 [259]).

He says further that

> A study of the non-water bearing strata of the Appalachian oil fields has furnished data which are to be interpreted as furnishing positive evidence that the waters present in these sands are connate in origin (p. 61 [259]).

If, as I believe, all sedimentary and igneous rocks above the zone of flowage have, in places, pores or cracks large enough for water molecules to get through (.00001 mm.?), water may migrate through the most impervious stratum, though the rate may be as low as a few inches per century, providing of course that there is a continuous column of water so that capillary forces do not affect the result. Such a notion is not at all out of harmony with the fact that certain oil and gas pools seem to be shut in very tightly, for it is evident that through differences in intermolecular attractions a fine-grained water soaked stratum, though pervious to water, may be absolutely impervious to oil or

[9] Reeves, Frank, "Origin of the Natural Brines of Oil Fields," Contributions to Geology, Johns Hopkins University, reprinted from *Johns Hopkins University Circular*, pp. 255–271, March, 1917.

even gas. Moreover, even oil and gas pools may not be quite so stationary as they appear to be. Perhaps many of them are in motion at an imperceptible rate.

It has thus seemed within the range of possibility that in the time since the deposition of the strata of the Appalachian oil fields, the salt water though approximately connate may have migrated a greater or less distance directly or indirectly toward the sea, which is 1,000 to 2,000 feet below the surface of ground water in the oil region and only 165 to 250 miles distant, or perhaps has moved even more directly downward toward the zone of flowage, if by any means water could there be taken up. The fact that in many sandstone strata fresh water is found to extend down the dip a few dozens or scores of miles to depths of 500 to 1,000 feet, and that beyond a somewhat narrow belt they contain salt water, seems suggestive that such a movement has taken place, the fresh water following the salt as it migrates downward, and moving altogether perhaps 20 or 50 miles in as many million years, or a few inches a century. It is surprising that diffusion has not made the gradation from salt to fresh water more extended and regular. Perhaps the fact that gas pools seems on the whole more abundant about the margins of the basin than in the middle may have a bearing on this suggestion the oil being pushed along more readily than the gas by the downward migrating water. In regions where fresh water is found abundantly at considerable depths, conditions are presumed to have differed in degree rather than in kind, the indigenous fluid water, with gas and oil if any was formed, having been replaced by fresh water. It should be borne in mind also that fluids below sea level may be subject to motion on account of hydraulic gradient.

May "dry" sands above sea level be beds that have been drained because they have good outlets but closed intakes, the pressure of the atmosphere and the friction of movement which tend to hold the water in, being overbalanced by the hydraulic gradient involving a pressure difference of 10 to 30 atmospheres or more? If this process took place we should have

frequent authentic reports of air rushing into a well when a sand is penetrated. Draining, through the using up of connate water by occlusion, adsorption and chemical change were all carefully considered and for a similar reason abandoned as a cause of deep dry sands before the validity of "dry" sand reports came to be doubted. Moreover, since "dry" sands are in the main below sea level, draining seems, as Reeves says, out of the question, though it might be possible if the region had once stood higher than now.

Reeves says that consolidation "could not decrease the percentage of saturation" and "heat apparently could have been no effective factor in removing the water."[10] While attempting to find the explanation of the reported dryness of sands I have often wondered if even heat changes and consolidation, along with all other processes leading to the squeezing out of water, might not lead to empty pores through some sort of valve action, for the forces tending to drive water out are as a rule greater than those tending to drive it back. It seems conceivable though very improbable that 200 atmospheres or more might be required to force water even at an extremely low rate through some layers of clay shale such as are often regarded as absolutely impervious, because of their content of plastic material mixed with solid grains of various sizes.

Conditions of Deposition of Catskill.—On page 367 Reeves says:

> During periods of little rainfall on the highlands the rivers did not occupy their flood plain and the sediments deposited there during the last period of flood were dried out and filled with air which prevented water from entering them again when the next season of rainfall caused the rivers to leave their banks and cover the plain.

Such a process is, so far as I am aware, quite unexampled and extremely improbable. Even under an arid climate, continental deposits, while accumulating, absorb what water they can from below and when flooded absorb slowly or rapidly water from above. Certain fine-grained silts and clays take

[10] Econ. Geol., vol. 12, p. 365.

up water slowly, but can an example be cited of a sand failing to imbibe water when submerged? It must be remembered that the entire area under discussion was under ocean water more than once, if not frequently, and over extended periods in Catskill time.

Additional Considerations.—At the surface of the earth we have to deal with pressures not far from 15 pounds to the square inch. If the pressure here should depart 2 pounds from this figure, there would be a most violent storm. We are so accustomed to living under and dealing with this essential condition of our daily life, that we too easily assume that similar conditions commonly affect the contents of rock pores within the earth. The most impressive part of experience with diving apparatus is the tremendous pressure in water only 50 or 100 feet deep. Even at 20 to 30 feet one's ear drums sometimes ache severely, though the pressure is only about 2 atmospheres, and the cause of caisson disease is said to be gas pressure in the blood, due to the change in external pressure of one or two atmospheres. Two atmospheres is about 2 tons to the square foot, but this is a small quantity compared with the pressures thousands of feet down in the earth. At the bottoms of the Clarksburg and MacDonald wells the pressure on the rock is roughly 500 tons to the square foot, or far above the critical pressure for water. What is the pressure in the rock pores at such depths? If the strata have connecting pores and cracks extending to the surface it should approach the weight of a column of water extending to the top of ground water and in deep wells where we have definite information it is generally not far from the hydrostatic head. The average is far nearer this amount than either the weight of the superincumbent rock or the weight of nothing but the atmosphere, and the departures are presumably due to one or more modifying factors almost certainly operative. It seems to me that it can not be too strongly emphasized that the occurrence of a pressure of one atmosphere in a sand one or several thousand feet below the surface would be so unlikely as to be practically beyond possibility, and the inference that such a pressure exists in hundreds

and even thousands of places becomes an absurdity. If the sand has large and open pores connecting with portions that are gas- or oil-bearing, the pressure should become equalized and some fluid should enter the well. On the other hand, if the pools are in parts of the sand shut off from other parts by some sort of barrier, the so-called dry sands may be either portions of the sand that are not impervious but are so sealed off from the surrounding fluid-bearing sands that they cannot readily yield the contents of their pores into the wells, or they may be tighter than realized, the pores being closed by cement or some plastic, clogging material.

Perhaps the most cogent argument against true dryness of the so-called dry sands is the fact that they do not contain air under great pressure, for it seems quite inconceivable that the connate air of an air-dried sand should remain at or near one atmosphere so that when penetrated, after having been buried millions of years under thousands of feet of water-soaked rock, no air should rush into or out of it.

EUGENE WESLEY SHAW.

THE GEOLOGIST IN WAR TIMES—THE TRAINING OF ARTILLERY OFFICERS.

Sir:—Scientific men feel that if possible the advantages of their specialized training should be placed at this time at the disposal of the government. With geologists the question is oftentimes a puzzling one, for their particular training is not of such obvious helpfulness as that of the surgeon, chemist, metallurgist, or civil engineer. There are, however, many fields in which his knowledge, training, and opinions are of value for war purposes. To those geologists who may not have had the matter brought to their attention, it is believed that these columns may be appropriately used to indicate some of the means, and one in particular, by which their services could be utilized if they desire to proffer them.

It has already been brought to the attention of geologists by the National Research Council and the Geological Survey that they can render valuable aid in the examination of properties

containing minerals essential for the manufacture of armament and munitions. Other uses of the geologist have been pointed out by R. A. F. Penrose in the booklet "What a Geologist Can Do in the War," issued by the geological committee of the National Research Council. It is shown that his knowledge of terraines, structure, drainage, water supply, topography, and maps can be utilized to advantage.

Nearly all geologists, regardless of their specialization, can assist in training artillery officers by teaching topography, map-making, and map-reading. The forming of the artillery service necessitates the training for officers of a large number of young men, all of whom must be capable of reading and constructing topographic maps. In this branch of the service the demand for instructors is at present greater than the supply.

The artillery officer must be able to read quickly topographic maps and form a mental picture of the ground. From them he has to pick out a position for his battery, as it is rarely possible for him to travel over the ground beforehand. Topographic features which will give protection for limbers must be learned from the map and the route of travel in occupying a new position. Guns must be so placed that if possible they will be protected by an elevated area in front of them, and yet sufficiently to the rear of it that the minimum trajectory can be used. The grade of a road must be determined and the steepness of a slope. One must know whether from a given point one can see over a hill to another point. This usually has to be done by constructing a visibility profile. The topographic map must be utilized to determine the elevations of the ground under fire and the differences in elevation between the battery and enemy positions. By means of horizontal and vertical distances, ranges are scaled off. Familiarity must be gained with graphic scales, R. F. or representative fraction scales $\left(\frac{1}{21120}\right)$, and those expressed in words or figures, as 1 inch 1 mile. Deftness must be acquired in changing from one scale to another, for example in finding the number of inches per mile of a map whose scale is $\frac{1}{31680}$. A

map with a scale in meters may have to be changed to yards or feet, and this requires a knowledge of construction of graphic scales.

The artillery officer may be required to enlarge a certain section of a topographic map and use it as a basis for more detailed sketching. Thus, an enlargement of a road that may be travelled, with the immediately surrounding country, is taken into the field, and details of the character of the road, bridges, streams, halting places off the road for horses and men, fences, fields, shelter, observation points, and camp sites sketched in. If the road contains mud holes or the bridges or culverts will not support heavy guns, the locality of materials for repair and reinforcements must be indicated. When a new position is to be taken an enlargement of that section is made and an officer sent ahead to fill in the necessary details. He must sketch in a larger number of contours, indicate the unevenness of ground, suitable positions for guns, shelter for limbers, horses, and ammunition, camp sites, and water. Such sketches may also have to be made without enlargements for a basis, a task which requires knowledge of control by pacing and compass and ability to indicate details in their proper proportions, all of which involves the rudiments of map-making familiar to all geologists.

The officer's training also includes the making of panoramic sketches. He may be detailed to an observation post, there to record accurately the panorama that extends before him and to produce a sketch resembling a panoramic photograph except that points for locations and of military importance are emphasized, and obscuring details left out. By use of horizontal and vertical angles read by a compass and clinometer, or by vertical and horizontal distances expressed in mils for artillery graduation, he must locate accurately the important objects. These are outstanding topographic features, railroads, roads, bridges, buildings, towers, fields, forests, military locations, and enemy positions. All of these items are sketched in perspective, and the important details fitted in. The immediate foreground is omitted and all minor details that add nothing, but tend to obscure the important objects, are disregarded. Remarks consist-

ing of a few words only give more information. They are added at the top of the sketch immediately above the points and not on the map itself. The finished sketch may be used to give a clear picture of the country fronting the guns. A glance will show the position of supporting batteries, limbers, camps, trenches, and enemy positions. From it, data to determine the direction of firing may be obtained. Probably its greatest use is to record ranges already determined, directly above the actual picture of the object. With numerous ranges thus recorded, rapid changes of firing may be made, for the position sought with the range marked above it may be picked out at a moment's notice. Accurate large scale topographic maps of the European battlefields already exist, so that there is little demand for their construction. Practically all the maps that may have to be made by artillery officers are sketches, necessitating few instruments and requiring rapid work.

It is in work of this nature that geologists are skilled. While not primarily topographers, all geologists have been trained or had experience in methods of mapping and sketching and must have recourse to it in their ordinary procedure of field work. Maps are their tools. Reconnaissance surveying especially calls for rapid mapping and sketching and gives them that particular knowledge so indispensable to artillery officers. Thus, with a group of men requiring special training to fit them as artillery officers and another group competent to give that instruction, is there not an opportunity for the geologist to be of service? Those who have wondered how their experience might be utilized by their government may find an answer in the suggestions indicated by this partial outline of training required for artillery officers.

The preceding outline suggests only one form of service that might be rendered by the "Geologist in War Times." Unquestionably many others are known, and it is hoped that these columns may be utilized for additions to the above discussion by those who have come in contact with other phases of the subject.

ALAN M. BATEMAN.

REVIEWS.

A Study of the Magmatic Sulfid Ores. By C. F. Tolman, Jr., and Austin F. Rogers, Stanford University Publications, 1916, 76 pp., 7 text figures, 20 plates

The development of the mines at Sudbury, Ontario, over thirty years ago, brought into the discussions regarding ore deposits a type that was new to American students of the subject. While similar but much smaller bodies had been long known in Norway, they did not become generally appreciated until the writings of J. H. L. Vogt were widely read in the early nineties. The sulfids are well-nigh universally pyrrhotite and chalcopyrite, almost always with nickel, now known to be in pentlandite. The occasional presence of small amounts of the platinum group gives added interest. Since the containing rock is generally a massive, unaltered norite or some related member of the gabbro family, and the ores are found in the outer edges of the intrusions, great or small, an interesting series of views received support, almost all involving the phenomena of crystallization from fusion. Considered in the large way, the relations to be observed in the mines first opened at Sudbury abundantly justified these interpretations which were expressed especially by A. P. Coleman. In time, however, the detailed study of thin sections, and, later, of polished slabs by metallographic methods, brought out a time succession in the minerals, both ore and rock-forming, and began to create in the minds of many the suspicion or belief that "after effect" phenomena, somewhat akin to the formation of pegmatite from granite magmas, were involved.

When the first party of the 12th International Geological Congress visited the mines in July, 1913, and had the great privilege of Professor Coleman's personal guidance, informal expression of these views was often made in the discussions on the spot. Now, moreover, that great ore-bodies are developed entirely outside the "nickel-norite," and especially as emphasized and illustrated in great detail by C. W. Knight in the recently issued report of the Ontario Nickel Commission, all must realize the importance of this new evidence and seek to adjust views of origin to correspond with it.

Professors Tolman and Rogers have undertaken, by microscopic and metallographic methods, the study of suites of specimens from as many

of the ore-bodies of the Sudbury type as were available. Not only have Canada and the United States contributed, but Norway, Sweden, Germany, and South Africa as well. While carried out along somewhat similar lines to the earlier paper of Wm. Campbell and Cyril W. Knight,[1] the observations embrace a much more extended series of ores. In ten years geological descriptions have greatly multiplied. Some observations and conclusions are also added on supposed igneous pyritic deposits; on the magnetic-ilmenites; on other magmatic iron-ores; and on chromite.

The authors prepare the way with an introduction in which the older theoretical views are summarized and their own particular conception of "magmatic processes" is carefully defined. They state (p. 5) the term "magmatic deposits" should be limited to those segregations of ore-minerals that take place under the influence of, or closely connected with, the molten stage of the parent rock. Ore accumulations accompanied by destructive pneumatolytic action, or those formed by hydrothermal solutions, are not classed as magmatic deposits, although they may be closely related to, and follow, the magmatic period of ore concentration. Inasmuch as ore concentration connected with persilicic ("acid") rocks are of the latter type, the typical magmatic deposits are confined to the subsilicic ("basic") rocks.

Again on p. 7, "our study of the magmatic ores has led us to frame the hypotheses that *the magmatic ores in general have been introduced at a late magmatic stage as a result of mineralizers, and that the ore minerals replace the silicates. This replacement, however, differs from that caused by destructive pneumatolytic or hydrothermal processes, in that quartz and secondary silicates are not formed at the time the ores are deposited.*" While the authors note that some indications of high temperature alterations of wall-rock minerals are to be observed, such as the change of pyroxene to hornblende, and that in the specimens as now collected at the mines even hydrothermal alteration does not absolutely fail, the ore deposition certainly precedes the latter. The association of the sulfids or of the iron-oxides or other oxides, with fresh and unaltered, although extensively "replaced" rock minerals, is the feature which keeps them within the magmatic type.

Three types of magmatic sulfid ore-bodies have been supported (p. 8): (1) pyrrhotite-chalcopyrite deposits in norite and gabbro; (2) chalcopyrite-bornite deposits in norite and diorite; and (3) the so-called intrusive pyritic ores. The third type the authors do not believe to be magmatic and in the end they conclude that "pyrite is not a typical magmatic mineral" (p. 71, paragraphs 13 and 16).

In Part I., which follows the introduction, the authors review the

[1] ECON. GEOL., 2: 350–366, 1907.

current ideas of magmatic differentiation in rock magmas, and fall in line with the now generally accepted views regarding acidic and basic products, and the final emission of the dissolved gases, liquids, etc., collectively described as mineralizers, together with the constituents of ores and associated minerals later than the wall rocks. The acidic rocks are the schist source of these evolved products; but in the formation of the magmatic ores of the types studied, the basic rocks have also yielded them. The mineralizers specially cited are (p. 10) chlorin, fluorine, boron, water, hydrogen sulphid, etc., and the process of replacement is believed to have taken place at quite moderate temperatures, probably not higher than 300°–400° C. (p. 16). Sulfur is also regarded as a mineralizer (p. 15) and in a footnote it is noted that petrographers do not usually consider it in this light. Yet the remark may be made by the reviewer that in the old use of the word mineralizer in the definitions of "ore," fifty years or more ago, sulfur and oxygen were the two most prominent elements described by this word. Thus ores were contrasted with native metals because in the former the metallic character was disguised by combination with a mineralizer such as sulfur or oxygen. The great change in the significance of the word mineralizer in later years is not without interest.

The authors conclude from their studies (p. 14) that there is an invariable succession in the formation of the minerals in the nickel-copper deposits, to wit: (1) silicates, (2) magnetite and ilmenite, (3) pyrrhotite, (4) pentlandite; and (5) chalcopyrite. In the chalcopyrite-bornite type the series is (1) silicates, (2) magnetite and ilmenite, (3) hematite, (4) pyrrhotite (when present), (5) chalcopyrite and bornite, but later, p. 71, paragraph 15, they state that pyrrhotite and bornite have not been found together. This interesting association or failure to associate seems to hold true even when at the same locality, Ookiep, South Africa, there are bodies of pyrrhotite-chalcopyrite, and of chalcopyrite-bornite ores. In general all alteration minerals except hornblende are later than ore deposition, and only very small amounts of the so-called "rearranged ores" have been recognized.

The authors attach much importance to the euhedral character of the magnetite which they interpret as of introduction subsequent to the crystallization of the silicates (pp. 20–21) and even go so far as to consider the accessory minerals of igneous rocks which are almost universally believed to be the oldest, viz., magnetite, ilmenite, apatite, titanite, zircon, etc., as probably of late introduction and due to mineralizers. The latter startling reversal of the natural conclusions which scores of careful petrographers have drawn from thousands of thin sections makes one realize that great caution is necessary in the interpretation of the observed phenomena. Reference will be again made to this phase of the

subject before closing the review. Part I. closes with a summary, under seven heads, of the successive stages in the formation and subsequent alteration of a magmatic ore-body.

In Part II., the details of the several ore-bodies and ores which have been studied by the authors are set forth. The main features of the local geology are summarized as are also the most important previous papers. The authors' own observations are then detailed, and are illustrated with a wealth of photomicrographs which, of both low and extremely high magnification and of great perfection in the art, constitute the seventy-seven figures of the twenty plates. Excellent bibliographies follow the descriptions of each ore-body. The cases studied embrace for the nickel and copper-bearing pyrrhotite deposits, Sudbury; Alexo Mine, Ontario; Friday Mine, San Diego County, California; Golden Curry Mine, Montana; Prospect Hill, Litchfield, Connecticut; Knox County, Maine; Mountain, Wisconsin; Insizwa Range, South Africa; Norway; Sweden; Baden, Horbach, Todtmoos, Sohland, and Sweiderich, Germany; for the chalcopyrite-bornite deposits, Ookiep, South Africa; and the Engels Mine, California. Part II. closes with remarks on the deposits of pyrite; of magnetite-ilmenite; of magnetites; and chromite which have been considered magmatic.

Part III. contains a review of the criteria for the recognition of magmatic ores, and a summary under thirty different heads of the authors' conclusions. All these thirty are of great interest and well deserve the careful attention of any student who takes up the investigation of similar ores and ore-bodies. Indeed, for the fulness of illustration and treatment, the authors are to be congratulated. The succession of the minerals in the ore-bodies is in most cases established beyond question. In this respect there seems to be no other interpretation to be put upon the phenomena *in most cases;* and yet for some a reader may hesitate to reverse his long-trusted standards of interpretation. Thus in petrographic work and for his students, the reviewer has been accustomed to sum up time relations as follows, and thereby has doubtless expressed the general beliefs of petrographers:

1. Later minerals include older minerals.
2. Later minerals cut older minerals.
3. Later minerals enwrap older automorphic minerals.

The first two rules of interpretation are followed by the authors, with the exception of the interpretation of small masses of sulfids or of magnetite entirely enclosed so far as one can see from the illustrations, in fresh and unaltered silicates. Instances of these relations are shown in Figs. 52, 53, 56, and 58. The extreme conclusion suggested by the authors, that all the members of the so-called group of the ore-minerals, generally

regarded as the first and oldest results of crystallization from magmas, *i. e.*, magnetite, apatite, titanite, zircon, occasional sulfids, etc., are the latest of all and due to replacement, seems to the reviewer to turn the natural, simple and reasonable interpretation upside down. Despite the emphasized influence of mineralizers, many will not be prepared to abandon the time-honored view, supported as it is by the experimental results of Lagorio, Morozewicz and others with dry melts. In the mention a second time of this matter, the reviewer does not wish to lay undue stress on what is obviously in the minds of the authors a minor feature; but it illustrates the extreme to which the supporters of replacement may go.

Regarding the third test of age, wherein minerals are believed to be later because they enwrap supposedly older, well-crystallized ones. Thus where well-terminated magnetite projects into a silicate, the authors infer replacement of the older silicate by younger magnetite; where long, slender prisms of tremolite project from silicates into sulfids, a replacement of the sulfid by the tremolite is the interpretation placed upon the relations. Yet a reader accustomed to place faith in the old standards and rules of interpretation cannot help feeling much hesitation and caution in abandoning them.

The authors appeal with confidence to the replacement of silicates by sulfids and oxides with the aid of mineralizers, and at temperatures of 300°–400° C. We may follow out this line of thought a little farther. The replacement process usually leaves the residue of silicates perfectly fresh and unchanged. The actual mineralizers mentioned are sulfur, chlorin, fluorine, boron, water, hydrogen sulfid, etc. At temperatures of 300°–400° C. and at conceivable pressures, water could not be entirely, if at all, dissociated. The sulfids of iron, copper, and nickel in order to penetrate such solid and finely crystalline rock as exists at Sudbury and elsewhere, and as is illustrated for the Engels Mine, in Fig. 72, must form with the assumed mineralizer either a gas or a very penetrating liquid, since, of course, entrance as a solid is out of the question.

In thinking over the authors' conclusions, one cannot help raising the question as to whether we have any actual knowledge that would lead us to believe that the above mentioned mineralizers, or any others which can be reasonably cited, can make a gaseous or liquid combination with these metallic sulfids, at the temperatures 300°–400° C. The question is raised by the reviewer in no captious spirit, but as a point which well deserves further and more definite elaboration. One is hardly justified in sweeping away all the difficult features of the problem by the mere appeal to mineralizers. On the face of the field relations, at least in some of the deposits, the conception originally suggested by J. H. L.

Vogt of molten sulfids, and elaborated later by Ernest Howe as involving immiscibe molten liquids, so as to explain the succession of the solidified sulfids in time, is not to be lightly rejected. The failure of reaction rims emphasized by our authors on p. 16, first paragraph, as fatal to this view, does not seem to the reviewer to be any more fatal than the failure of any rim alterations in the silicates from the processes of replacement with the aid of mineralizers is to their own views. Very liquid products of fusion could penetrate shattered rocks and individual minerals, enwrap and not corrode them.

When the sulfids and magnetite form minute and uniformly distributed components in a rather finely crystalline, unaltered, and uncrushed igneous rock, they certainly look like early and original crystallizations from fusion, just like ordinary components.

When, however, the sulfids greatly and abnormally enrich the rock mass, and appear in large masses, and are associated with evidences of brecciation, introduction from outside sources is more easily understood. Without the possibility of serious objection, one may reflect on the entrance in a fused, in a gaseous, or in a dissolved condition.

Additional and important evidence has been brought out by C. W. Knight in the recently issued report on the Ontario Nickel Commission. Knight shows the quite abundant presence of quartz in one or two of the large ore-bodies, and of an extensive quartz vein in intimate association with the ore. The great development of ore outside the nickel-norite in some of the largest mines is specially emphasized by him and he is led to their explanation along the lines of introduction by hydrothermal processes. After reading Knight's descriptions, one begins to wonder if some of the granite intrusions can be altogether barred out as factors in the ore-deposition, considered in the large way.

J. F. KEMP.

Postscript.—After the completion of the above review, the copy of ECONOMIC GEOLOGY for August came to hand, containing the additional papers of A. M. Bateman and A. P. Coleman on Sudbury. Although to be published later, the remarks above made may be left unchanged and perhaps do not lose in interest in the light of these two contributions.

J. F. K.

Conservation in Use of Coal. COMMITTEE ON COAL CONSERVATION, Bulletin II. to Owners and Managers of Power Plants. Ernest R. Trigg, Chairman.

The bulletin, issued as a four-page circular, is of interest to those readers of ECONOMIC GEOLOGY who maintain power plants. In it some methods are pointed out by means of which coal may be conserved.

Conservation of coal is of importance at any time, but during the present shortage and increased demand for manufacturing, it is vital. The steps to an owner or manager are here quoted.

"*Reconsider the Advantage of Buying Heat and Power* from a specialized plant that makes nothing else and can afford the investment and supervision that gets a maximum of value out of each pound of coal; in some localities hydro-electric power may be available.

"*Find the Nearest Source of Coal* that will meet the requirements, even if it does take a little more trouble to use it; the tax on the transportation system will thus be reduced so far as haulage by rail is shortened; coal is mined in twenty-six states, and these states extend practically across the continent and from the northern to the southern borders.

"*Give to the Power Plant and its Personnel Recognition and Encouragement* such as is due an expert and important department, thus getting new effort and attention to offset the extra attention and care needed with coal inferior in grade and preparation to the coal formerly available.

"*Seek to Increase Skill and Proficiency* in the men who handle the coal; a fireman at a hand-fired boiler shovels three to ten tons of coal a day,—or as great a value in material as many skilled men in other departments.

"*Put the Fuel-using Equipment Into as Perfect Condition as Possible;* provide at hand-fired plants an ample firing floor with a good surface, together with a smooth-bottomed coal car if it can be used; eliminate leaks in the boiler setting, see that fire-doors fit properly, replace defective grate bars, make sure that smoke connections are clean and tight; if mechanical stokers are used, see that they are in good repair and that directions for using them are being followed; in general, make the plant and the fire-room of such character that an efficient man will stay on the job.

"*Install Simple and Convenient Means by Which the Fire-room Force May See Results;* scales for weighing fuel and ash, meters for measuring water fed to the boiler, and devices for determining the quality of flue gases, the draft over the fire, etc., can be made to interest the men in the fire-room and show the actual results of efforts to economize; convenient means for operating the flue damper must be installed.

"*Endeavor to Run Boilers in Service at their Capacity;* if efficiency is increased, one or more boilers in a battery may be dropped.

"*Provide Water that is Free from Scale* by using, when necessary, water-treating devices if the plant is large and special feed-water heaters in small plants.

"*Reduce Loss of Heat After it is Generated;* see that boiler surfaces and steam pipes are properly covered; the simplest and most inexpensive covering will reduce loss by eighty per cent.; in the engine room cut out useless steam lines, have valves properly set, reduce the small auxiliary pumps, etc., to a minimum, provide the repairs the engineer has been asking.

"*Obtain Expert Advice;* good steam engineers are familiar with well-tried ways of reducing both consumption of coal and consumption of heat; their advice should be obtained in all practical cases; this is not a time for radical innovations but for utilizing tried experience.

"One pound of coal per hour has yielded a horsepower per hour. That is the record of present possibility. It cannot by any manner of means be attained by every plant. But the fact that at present the average attainment throughout the country is but one third or one fourth of this record is indicative of the possible savings that can be made if the care and attention which the power plant deserves are actually given to it.

"The suggestions which have been given above are typical of the points about which every owner and manager of a power plant should assure himself. The applicability of any general suggestions will vary with nearly every plant.

"Most users of coal can join in promoting efficiency of coal. Railways have made real progress in firing locomotives; they can often go farther. Gas works can generally effect future saving by using careful technical direction. Manufacturing plants of every degree can show great results in the aggregate."

It is pointed out that the Bureau of Mines has published information regarding the use of coal and means of economy, which may be obtained from them free of charge.

ALAN M. BATEMAN.

SCIENTIFIC NOTES AND NEWS[1]

THE WEST VIRGINIA GEOLOGICAL SURVEY has just issued a Detailed Report on Clay and Braxton Counties giving valuable information on the coal, oil, gas and minerals of that section of the state.

PROFESSOR H. P. PATTON, of the Colorado School of Mines, has opened an office in Golden for consultation work.

ERNEST HOWE has recently returned from South America and is at present engaged in the investigation of properties for the Council for National Defense.

F. J. SUR, of Denver, has recently been carrying on investigations in Wyoming and Kansas oil fields.

R. E. SOMERS, of Cornell University, spent the past field season in oil investigation in Kentucky.

W. C. BEAN and L. P. TEAS, assistants in geology at Cornell University, have been appointed geologists with the Medina Gas and Fuel Company of Ohio.

WARREN D. SMITH and E. L. PACKARD, of the Department of Geology of the University of Oregon, investigated the general geology and chromite deposits of the John Day Valley and the gold deposits of Baker during the past summer. Mr. Smith also examined some platinum, coal, gas and salt in Oregon.

MYRON FULLER, formerly Chief of Eastern Hydrology, of the U. S. Geological Survey, has accepted the position of Chief Geologist of the Sun Company. Associated with him are R. W.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Pack, F. H. Kay, L. B. Smith, Bernard Hasbrouck, John Cullen, and G. W. Myers.

L. D. RICKETTS is in charge of the mining and geological operations of the Calumet and Arizona Mining Co., during the absence of J. C. Greenway, who has joined the colors.

F. L. RANSOME will take up work pertaining to quicksilver, formerly handled by H. D. McCaskey, in order to allow Mr. McCaskey more time for administrative work.

L. C. GRATON has been absent from his desk for some little time due to an injury to his foot and illness contracted from a severe cold.

AS INFORMATION regarding the activities and whereabouts of those interested in applied geology, who are at present engaged in military service, is desired by readers of the journal, the editors would appreciate immediate receipt of such news so that it may be regularly incorporated as a part of the "Scientific Notes and News Section."

ANNOUNCEMENT.

THE Bureau of Mines announces, that the scope of the experiment station at Urbana, Ill., is broadened to include studies of technologic problems in both coal and metal mining and in metallurgical industries, in addition to continuing its present work relating to improvement of safety conditions and practices in mining. It will be headquarters for work in the middle west district. Coöperation is maintained with the Illinois State Geological Survey and the Mining Department of the University of Illinois, thereby securing the services of engineers, geologists, and metallurgists. E. A. Holbrook, formerly professor in the Mining Department of the University, has been appointed Supervising Mining Engineer and Metallurgist and will act as superintendent of the station. W. B. Plank, formerly of the Pittsburgh Station, is now at Urbana and Frank K. Ovitz will continue his chemical work on coals.